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Report
of the
Kansas Board of Irrigation Survey and Experiment.

1895-'96.

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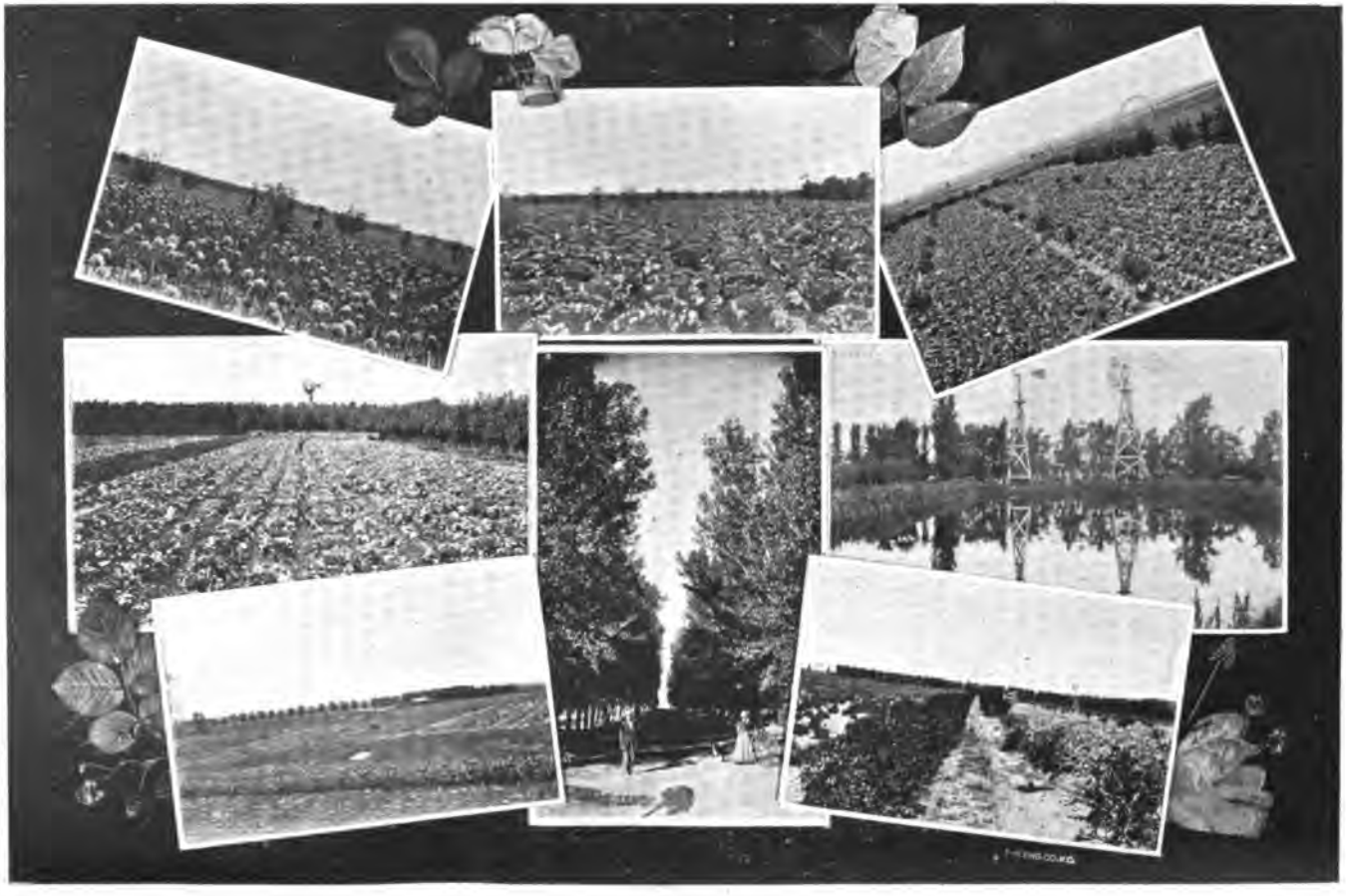

IRRIGATION FARMING IN FINNEY COUNTY.

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REPORT

OF THE

Board of Irrigation Survey and Experiment,

FOR

1895 AND 1896,

To the Legislature of Kansas.

TOPEKA.
THE KANSAS STATE PRINTING COMPANY:
J. K. HUDSON, State Printer.
1897.

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THE BOARD OF IRRIGATION SURVEY AND EXPERIMENT.

APPOINTED BY THE GOVERNOR.

D. M. Frost, *President*, ... Garden City.
M. B. Tomblin, ... Goodland.
Wm. B. Sutton, *Secretary*, ... Russell.

ADVISORY MEMBERS DESIGNATED BY THE STATUTE.

Geo. T. Fairchild, President State Agricultural College, Manhattan.
Erasmus Haworth, Professor of Geology, University of Kansas, Lawrence.

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To the Legislature of Kansas:

The Board of Irrigation Survey and Experiment, whose existence was provided for by chapter 162, Laws of 1895, in obedience to the provisions thereof has prepared a full report of its proceedings and investigations, observations and experiments, including an account of all funds received and disbursed to January 8, 1897, which report is herewith respectfully submitted.

D. M. FROST,
WM. B. SUTTON,
M. B. TOMBLIN,
Active Members.
GEO. T. FAIRCHILD,
ERASMUS HAWORTH,
Advisory Members.

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REPORT.

INTRODUCTION.

WM. B. SUTTON.

The tide of immigration into Kansas, beginning immediately after the war, had swept steadily westward until in the latter 80's it had reached and covered the state to the Colorado line.

These settlers brought with them the breaking plow and other agricultural implements, and set to work to reduce the whole state to cultivation. They made a brave struggle to maintain the position they had taken and to demonstrate the theories they had evolved but were gradually beaten back, and for years past the covered wagon– prairie schooner–headed eastward has been a common sight on the western Kansas highways.

In 1889, according to the census of the State Board of Agriculture, the population of the state west of the 100th meridian was 81,279, the same territory in 1895 according to the same authority held 49,850 souls.

The cause of this is soon told. The settlers attempted to farm as they had done in eastern Kansas and in the states from whence they came and it did not prove profitable.

Kansas, like ancient Gaul, is divided into three parts, the eastern, middle and western. There is a gradual increase in elevation from east to west and a gradual diminution of the amount of rainfall.

The crop conditions of the eastern part of the state compare favorably with those of any agricultural section. Those of the middle while not so favorable as the eastern, are such that the frugal industrious farmer steadily betters his condition and eventually acquires a competence and in very many instances achieves signal success.

The condition of the farmer in middle Kansas, when all the advantages are ranged on one side and disadvantages on the other is as good as or better than, that of the farmer of almost any other section of the union.

In the western part it is different. The altitude has increased to about 2,500 feet on the east side and about 3,000 to 4,000 feet on the west side. Timber has also disappeared entirely from the uplands and but little is found along the valleys. The rainfall has decreased to 15 or 20 inches per annum and but little water flows in the stream beds except in time of floods.

General farming of staple crops under these conditions is in the majority of years unprofitable, and years of abundance are too far apart to bridge over the failures. The soil is not at fault and the climate is most congenial to out door life, but these alone are not sufficent to sustain a dense population.

The natural product of nearly the whole territory is buffalo grass which cures in the fall and furnishes a most nutritious food for stock during the winter.

The one thing lacking seems to be water. About 1890 the subject of irrigation in the western third of the state began to be agitated and a convention was held at Great Bend to consider the subject.

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A state organization was effected and the subject since then has been discussed in conventions, through the press, and among the people.

The federal government had done some work in the direction of investigating the subterranean waters of this section but not enough to warrant many definite conclusions on the subject.

In this condition of affairs the state legislature in the session of 1895 passed a law providing for an irrigation commission and appropriated the sum of $30,000 for the purposes of the act.

The following is a copy of the act which is known as

THE IRRIGATION LAW.

(Chap. 162, Laws of 1895.)

An Act relating to irrigation and providing for the creation of a Board of Irrigation and the manner of appointment, and defining the duties thereof, directing that certain experiments in irrigation be made and making an appropriation therefor, and for these purposes withdrawing certain school lands from sale, and providing for the state to take and hold certain lands for the purposes of this act.

Be it enacted by the Legislature of the State of Kansas:

Section 1. That a board to be known as a Board of Irrigation Survey and Experiment is hereby created, and said board shall be composed of five members, two of whom shall be the geologist of the State University at Lawrence, and the president of the Agricultural College at Manhattan, who shall be advisory members of said board, and three members to be appointed by the governor, by and with the advice and consent of the senate of Kansas; who shall hold their office for the period of two years, not more than two of whom shall belong to the same political party and may be removed for cause; said last mentioned three members to be appointed during the present session of the legislature and said board to meet and organize within ten days after the confirmation of the said third, fourth and fifth members; the last mentioned members shall be persons versed in practical irrigation, and to be active members thereof. The said board shall have charge of the work contemplated by this act. Said board, for the sake of brevity, is hereinafter referred to as the Board of Irrigation.

Sec. 2. The active members of said board shall take and subscribe to an official oath faithfully to perform the duties imposed by this act. When said board shall organize and shall give bond in the sum of five thousand dollars each, subject to the approval of the secretary of state, the members thereof from their number shall select the president and a secretary of said board. The president shall be known as the state engineer of irrigation.

Sec. 3. Said board shall hold its meetings at the city of Topeka quarterly, and its meetings shall be held at the rooms provided for the state board of agriculture, and it shall also hold meetings in the territory wherein the work of the board is being performed, at such places as the board may designate, due notice of time and place of meeting being given in some newspaper published in the county wherein such meeting is to be held, a majority of active members to constitute a quorum.

Sec. 4. All surveys and records thereof required by this act shall be under the charge and direction of said board.

Sec. 5. In order that there may be made a practical test of the water supply on the uplands of western Kansas for irrigation purposes said board shall cause to be constructed twenty irrigation wells and pumping stations or more

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if possible under this appropriation, not more than one of which shall be located in the same county, which shall be constructed and operated under the direction of said board in such manner that correct data of the depth of wells, quantity of water supply, kind of pumps and power employed, and the capacity of each of said wells, and said board are hereby empowered to make a practical test of the so-called underflow water for the purpose of utilizing said underflow water for irrigation purposes, to make a full and complete examination of said underflow water as they may be enabled to do with the means placed at their command to demonstrate the best method of raising water to the surface and storing it for irrigation purposes, making as full and complete report of their investigations in detail, method and system employed, extent of flow of water supply thus secured, the availability of such water supply to be utilized, also to make observations, measurements and experiments to determine the quantity of water flowing annually in the streams west of the 98th meridian. And the amount of run-off or surface water and the practicability of storing the same for irrigation purposes in irrigating large areas and the probable cost per acre for such water supply and the extent to which it may be utilized: Provided, That no money shall be expended for the purchase of land, erection of permanent buildings, or experimental farming.

Sec. 6. There shall be prepared a full and complete drainage map or maps with profiles of the drainage basins and such other portions of said surveys necessary to carry out the intention of this act. The said map or maps shall represent the topography, flood areas, geographical [geological] structure, and all other details essential to as complete a knowledge as possible of the practical condition of irrigation in Kansas west of the 98th meridian. Said map or maps shall be executed on a scale of two miles to one inch, and be based on the section line and township outlines of the official land survey.

Sec. 7. The said Board of Irrigation shall cause to be made such station observation of rainfall, temperature, evaporation, and soil percolation as it may deem necessary for a more complete knowledge of all the conditions pertaining to water supply for irrigation within said drainage basin west of the 98th meridian: Provided that no part of the money hereby appropriated shall be used for these purposes to the prejudice of the underflow, sheet water and artesian work.

Sec. 8. Said board may cause to be made borings or drillings for artesian water and locate storage basins in connection with said wells at such points as said board may deem most practicable. A complete record of such borings and drillings shall be preserved in the same manner and with the same details as in the case of the underflow and sheet-water borings hereinafter mentioned.

Sec. 9. It shall be the duty of said board, in the construction of said wells, to keep accurate data of each stratum and sub-stratum and the depth or thickness of each passed through in such construction and preserve a sample of each in duplicate, one to be retained by the Board of Irrigation, and the other to be used by the state in determining the geological formation of the territory wherein such wells and stations may be located. And there shall be made to said Board of Irrigation a monthly report by the State Agricultural College of the work being done at the experimental stations under its charge and control.

Sec. 10. There shall be deposited with the State University, the State Agricultural College, and the Board of Irrigation, a true and correct copy of

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each and every survey and profile, field notes, plat, map or maps thereof, as soon after the originals are made as possible; the originals shall be kept as public property of the state wherever the Board of Irrigation may direct.

Sec. 11. It shall be the duty of the board in selecting sites and locations for said stations and wells, to locate the same upon the unoccupied school lands of the state where practicable, if there be such in the county wherein such stations shall be located. In the event that no unoccupied school lands shall be available to locate any such wells or stations in any county wherein such station or well shall hereinafter be located as hereinbefore provided, then said board shall receive donations from any municipal corporation, corporation, company, association, individual or individuals, of a sufficient quantity of land, not less than forty acres, upon which to locate such station or well, and before such station or well shall be located thereon a good and sufficient warranty deed shall be made to the state of Kansas, for said lands, and it shall be the duty of said board to investigate the title of said land and ascertain that the same is perfect. And said board may call to their assistance any county attorney in the state to assist in perfecting the title to any such land, and it is hereby made the duty of each county attorney to perform such services, and no money hereby appropriated shall be paid for the purchase of land under any event: Provided, That the state is hereby empowered to take and to hold any such land for the purposes herein indicated.

Sec. 12. For the purposes of this act all the unoccupied school lands of the state west of the 98th meridian are hereby withdrawn from sale for the period of two years, and shall only be placed on sale again by the order of the state superintendent of public instruction, the price at which said lands shall be offered for sale to be fixed by the state superintendent of public instruction, the secretary of the state board of agriculture and secretary of state, with special reference to the improvements thereon, then to be sold on competitive bids at not less than the value fixed in accordance with the law governing the sale of school lands.

Sec. 13. It shall be the duty of said board in prosecuting the work of constructing said stations and wells, to advertise for sealed proposals for thirty days in the official county paper where said station or well is to be located and to let the same to the lowest responsible bidder, reserving the right to reject any and all bids, the contractor to furnish a good and sufficient bond, payable to the state of Kansas, in a sum equal to double the amount of the contract price for constructing any such well or station, and there shall be retained twenty per cent. of the contract price until thirty days after the completion of said well and shall not be paid until such contractor shall furnish to said board authentic receipts for all work or labor performed and for material furnished in the construction of any such station or well: Provided, that in each and every contract made by said Board of Irrigation, all things being equal, it shall let the contract to the person or persons living nearest the location of the work to be done.

Sec. 14. The Board of Irrigation shall make a full report of their proceedings to the legislature at its next session, which report shall include an account of all funds received and disbursed by them showing the details of all expenditures, to whom and for what purposes paid. There shall be embodied in this report, in addition to the foregoing requirements, such other matters relative to the subject of this act as said board shall unanimously order and none other.

Sec. 15. Each active member of said board shall receive for his services the

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sum of ten hundred dollars per year, which shall be paid in quarterly installments by the state treasurer on the warrant of the state auditor, and each shall be entitled to actual expenses for transportation in the performance of his duties.

Sec. 16. The payment of all moneys under the provisions of this act not hereinbefore provided for shall be upon vouchers duly sworn to and approved by the board and payable by the state treasurer upon the warrant of the state auditor.

Sec. 17. It shall be the duty of said board, upon completion of such stations and wells to lease or sub-let the same to responsible parties upon such conditions and terms and under such rules and regulations as the board may prescribe.

Sec. 18. To carry out the provisions of this act the sum of thirty thousand dollars (30,000), or as much thereof as may be necessary, is hereby appropriated out of the funds in the state treasury not otherwise appropriated.

Sec. 19. All acts or parts of acts in conflict with the provisions of this act are hereby repealed.

Sec. 20. This act shall take effect and be in force from and after its publication in the Topeka Daily Capital.

COMMENTS ON THE LAW.

The student of this act will be bewildered by its ample commands, and meager appropriation for the purposes intended. The original bill provided for $50,000 which was reduced to $30,000 without any decrease in the requirements of the work; a very high authority upon work of the character contemplated by this bill, (Prof. F. H. Newell, Chief Hydrographer U. S. Geological Survey,) very soon after its passage, in a letter to the Board uses this language: "A copy of the irrigation act, passed by the Kansas legislature, has just been received. The act, I note, instructs your board to do an extraordinary number of things, all of which cannot be satisfactorily accomplished for many times the sum appropriated; but I suppose you will try to do those things deemed most essential and which will yield the most immediate results."

The following is a list or analysis of the most important things which the bill provides to be done.

1. To construct twenty or more irrigation wells and pumping stations on the uplands, keeping correct data of the depth of the wells; quantity of water supply; kinds of pumps and power used; capacity of each of said wells.

2. To make a practical test of the so-called underflow water for irrigation purposes.

3. A full report after complete examination of the underflow water.

4. To demonstrate the best method of raising water to the surface, and storing it for irrigating purposes.

5. To make a detailed report of results in raising water.

6. To make observations, measurements and experiments to determine the quantity of water flowing annually in the streams west of the 98th meridian.

7. The amount of the run off or surface water, and the practicability of storing the same for irrigation purposes.

8. The probable cost per acre, and the extent to which it may be utilized.

9. No money shall be expended for the purchase of lands, erection of permanent buildings, or experimental farming.

10. The preparation of a full and complete map or maps with profiles of the drainage basins, etc., showing "topography flood areas, geographical [geological]

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structure, and all other details essential to the complete knowledge of the practical condition of irrigation in Kansas west of the 98th meridian," all executed on the scale of two miles to the inch, and based on the official survey.

11. Station observations of rainfall, temperature, evaporation and soil percolation necessary to a complete knowledge of all the conditions pertaining to water supply for irrigation west of the 98th meridian.

12. To make borings or drillings for artesian water, and to locate drainage basins.

13. To keep accurate data of each stratum and sub-stratum, and the depth or thickness of each, and preserve samples of each in duplicate.

14. To deposit with the State University and State Agricultural College a true and correct copy of each and every survey and profile, field notes, plat, or map.

15. To locate the stations and wells upon unoccupied school lands where practicable.

16. To receive donations of land not less than 40 acres.

17. In prosecuting the work of constructing stations and wells to advertise for sealed proposals for 30 days, and to let the same to the lowest responsible bidder, reserving the right to reject any and all bids, and all things being equal to let the contract to the person living nearest to the location of the work.

18. To make full report to the next legislature, embracing their proceedings and such other matter as all the commissioners agree upon.

19. To lease or sublet the stations when completed to responsible persons.

APPOINTMENT AND ORGANIZATION OF BOARD.

On the 6th day of March, 1895, the senate confirmed the appointment by Gov. E. N. Morrill of D. M. Frost, of Garden City, M. B. Tomblin, of Goodland, and Wm. B. Sutton, of Russell, as members of the Board of Irrigation, and on the 7th day of March they were each duly commissioned by the governor as such and immediately entered upon the discharge of their duties.

The Board met in the rooms of the secretary of agriculture in the capitol on the 13th day of March, 1895. There were present Geo. T. Fairchild, president of the state agricultural college, Manhattan, Kas., Erasmus Haworth, professor of geology, state university, Lawrence, Kas., D. M. Frost, M. B. Tomblin, and Wm. B. Sutton. The Board organized by electing D. M. Frost president and Wm. B. Sutton secretary, which organization has continued.

SCOPE OF WORK.

The Board realized at once the impossibility of doing all that was embraced in the act with the appropriation made, and after repeated consultations decided to attempt the following:

1. To sink 20 wells and erect 20 stations, and test the yield therefrom as far as practicable.

2. To find the boundaries of the underflow waters, and map the same with as much detail as the means at hand would permit.

3. As far as possible to ascertain the depth of, and quantity of water furnished by, the underflow.

4. To measure the quantity of water flowing in the streams west of the 98th meridian.

5. To institute accurate tests of the efficiency of different forms of pumps designed to lift water from wells.

6. To gather accurate statistics as to the extent of irrigation west of the 98th meridian.

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As a preliminary step the territory was divided into three districts. The northern one, consisting of the two northerly tiers of counties, was assigned to Mr. Tomblin; the middle one, consisting of the next two tiers of counties, was assigned to Mr. Sutton; and the remaining counties to Mr. Frost.

Stations were located in the following counties: Rawlins, Sherman, Rooks, Trego, Logan, Wallace, Greeley, Wichita, Lane, Hodgeman, Hamilton, Grant, Haskell, Gray, Ford, and Seward; and were numbered one to nineteen, inclusive.

SPECIFICATIONS.

It was determined that a pumping station should consist of a well, pump, power to operate pump, and a reservoir for the water.

Specifications for the construction of these were prepared, a copy of which in blank is as follows:

WELL.

To be located at the spot indicated by the Board, and to be of sufficient diameter to receive a 6-inch vertical, tubular well-pipe, and to be perpendicular. Depth to be ..... feet more or less, and to reach to the bottom of the lowest water-bearing stratum when practicable and so ordered. The contractor shall keep (on blanks furnished by the Board) accurate data of each stratum and substratum passed through, the depth and thickness of each, and preserve a sample equal to at least a 6-inch cube of each. He shall box these samples, correctly numbered to correspond with the numbers of the strata in the order in which they are encountered, and shall ship these samples by freight, from the nearest railroad station, consigned to the State Board of Irrigation, Topeka, Kas. The receipts for these boxes shall be forwarded with a detailed statement of the number, depth and thickness of the strata, to said Board. The bidder must examine the ground for himself, judge for himself as to the materials to be encountered, and make his bid accordingly, and no bills for extras will be allowed under any circumstances. The amount of the bid shall include pulling the casing up to the top of the strainer after the latter has been put in place by the pump contractor. If galvanized-iron casing is necessary, the extra charge for same shall be specified in the proposal.

CASING.

There will be furnished to the well contractor, to be properly put in place by him, standard wrought-iron lap-welded pipe for the well casing, which shall be of six inches inside diameter, and of suitable tested strength, with the necessary standard couplings. The casing shall be delivered to the well contractor at the site within 10 days after award of contract for same. Delay in delivery of casing shall work penalty same as below. The well to be completed and the casing properly in place (except the pulling up of same) within 20 days after the award of the contract. The state of Kansas will retain a penalty of $10 for each day after the specified time until the contractor's work shall be properly completed, as and for liquidated damages. Time is of the essence of this contract.

PUMP.

The pump shall be of an approved pattern, having capacity equal to a cylinder of 5½ inches diameter and 42 inches length, with valves and connections capable of lifting the cylinder capacity of water as per stroke applied. The pump shall be of the best and most durable material, below which shall be fitted a suitable strainer of the largest diameter practicable, and of some standard or approved pattern. Rods connecting plunger to power shall be

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of suitable material and strength. Pump, cylinder, strainer and rods to be fully described in the proposal. Above the casing there shall be erected a stand-pipe extending two feet above the height to which water is to be pumped, furnished with T spout and substantially supported pipe or flume of suitable size and length to carry water beyond the foot of the inner slope of the reservoir embankment, which point of discharge shall not be more than 25 feet from the well. Top of well to be provided with pit 4 feet by 4 feet, 6 feet deep, cribbed and covered with 2-inch plank, cover to have manhole. Casing to be provided with cock 4 feet below surface of ground, and tool for opening and shutting same. The plunger connections shall be furnished by the pump contractor, complete, to a point above the top of the stand-pipe, which point will generally be about 7 feet above the surface of the ground. The cylinder strainer shall be of such length as the Board shall determine, and shall be closed at bottom to the satisfaction of the Board. The strainer, pump, cylinder, plunger and all connections shall be in place and in working order within 15 days after the completion of the well contract. The state of Kansas will retain a penalty of $10 for each day after the specified time until the contractor shall have completed his work to the satisfaction of the Board, as and for liquidated damages. Time is of the essence of this contract.

WINDMILL.

Windmill to be of suitable size, strength and durability to operate the pump to the fullest extent of the cylinder capacity, as per stroke applied, and to run in winds of from 10 to 40 miles per hour. Mill to be described in proposal, giving diameter and power. Tower to be of suitable strength, 40 feet in height, founded on suitable anchor posts at least 6 feet in ground, the feet of which shall be suitable plates. Proposal to include accurate specifications of tower. All of the above to be of the best material and construction, and to be fully warranted for one year, and guaranteed to do the work required by these specifications. At the option of the Board, the mill shall be operated under the management of the contractor for 30 days after completion before final acceptance by the Board. The contractor shall furnish the necessary wrenches and the usual extras. The mill is to be erected and in working order within 15 days after the completion of the well contract. The state of Kansas will retain a penalty of $10 for each day after the specified time until the mill shall be complete and in working order, as and for liquidated damages. Time is of the essence of this contract.

GASOLINE ENGINE.

The engine shall be provided with and set on a suitable foundation, properly connected to pump, with suitable jack and have ample power and be guaranteed to work satisfactorily for a period of one year. Any parts of same which may be found to be defective within that time, either as to material or workmanship, shall be replaced in working order by the contractor at his own expense. The engine shall be thoroughly well-built in every particular, and neatly and attractively finished. Shaft and connecing rod to be of forged steel. Main bearings to be of approved pattern and materials of ample diameter and length, with adjustable brasses at crank and wrist pins. Engine to be complete in all details, including the following items: Necessary oil cups; one galvanized steel supply tank for gasoline, having a capacity of 53 gallons; necessary piping for connecting gasoline tank 20 feet away from the engine, fitted with proper ignition attachments; 20 feet of exhaust pipe; a galvanized

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iron circulating tank for water (to keep cylinder properly cool) and of sufficient capacity therefor. The main gasoline supply tank (excepting the pipe through which it is filled), as well as the pipes from this tank to the engine (excepting the portion of the pipe within the house), shall be underground. The contractor shall furnish oil can and necessary wrenches. Bidder shall give detailed specifications of engine, jack and connections, and shall state actual and indicated horse power of engine. After completion and when in working order the engine shall do two days' pumping of 10 hours each at the expense of the contractor and to the satisfaction of the Board. The engine to be in place complete and in working order within 10 days after the completion of the well contract. The state of Kansas will retain a penalty of $10 for each day after the specified time until the engine shall be complete and in working order, as and for liquidated damages. Time is of the essence of this contract.

RESERVOIR.

The reservoir shall be of the following dimensions: 80 feet north and south, and 125 feet east and west, inside, bottom measurements. The above space and a margin 12 feet in width all around the same (if sod) to be plowed with breaking plow and sod removed; the entire area to be then plowed and scraped out on a grade from surface of ground on outer sides to a depth of three feet below surface in center. The entire area shall then be plowed four inches deep, thoroughly harrowed and pulverized into dust, and saturated with water to the depth of the plowing. Water shall then be shut off and bottom tramped evenly and hard with horses till their tread makes no impression. In case the area be sand, and the Board shall so order, the contractor shall cart in a depth of 4 inches of clay loam or black soil, which shall be used for puddling. The embankments shall then be built four feet high, outside measurement, of the earth previously removed, 12 feet wide at the bottom, two feet on top, and regular grade, and shall be saturated with water as they rise. Bottom and sides shall be made water-tight. Sod shall not be used within four feet of the center of the embankment. The sides and top of embankment, and inside of same to within three feet of bottom, to be neatly and evenly sodded with living sod three inches thick. The reservoir shall have two outlet pipes and valves not less than six inches in diameter, with suitable and satisfactory apparatus to operate the same from the ground outside of embankments, to be on a level with outside ground and located as directed. The pipes to be put in place before the embankment is started, and the bank to be thoroughly puddled under and about them. The valves and pipes will be furnished to the contractor at nearest railroad station. The reservoir, including pipes and valves, to be complete within 20 days after the pump is started. The state of Kansas will retain a penalty of $5 for each day after the specified time until the contractor shall have completed his work to the satisfaction of the Board, as and for liquidated damages. Time is of the essence of this contract.

GENERAL.

Notification in writing from the Board, through the Secretary, to the bidder, that any of his bids has been accepted shall make him contractor for such portion or portions of the work; subject, however, to the acceptance by the Board of the contractor's bond, which must be furnished within 10 days. The work to be done in accordance with such of these specifications as pertain thereto. In case bidder fails to furnish satisfactory bond, Board will let contract to another bidder. Any contractor may, at his option, tender a bid,

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upon the blank lines left for that purpose, for the entire pumping station, or for any part or division thereof, other than as herein divided. Any bidder may, at his option, append additional specifications for any portion of the work or materials. The Board reserves the right to reject any or all bids. Each bid, except for well or reservoir, must be accompanied by a certified check for the sum of $25, payable to the state of Kansas, as a guaranty that the bidder, if awarded the contract, will furnish to the Board, within 10 days thereafter, a satisfactory bond to insure the completion of the work under the contract. The amounts named in proposals are to cover all expenses incurred by the contractor, or chargeable to the Board, whether for labor, material, freight, drayage, or of whatever nature. The Board will retain 20 per cent. of the contract price until 30 days after the completion of the work, and until the contractor shall furnish to the Board authentic receipts for all material and labor entering into the construction of that portion of the station covered by this contract. No bills for "extras" shall be allowed to the contractor under any circumstances, unless authorized by the Board in writing. All material, mechanism and workmanship entering into the construction of the station, or any part thereof, must be first-class in every particular, and satisfactory to the Board or its agent in charge duly authorized in writing. Any pipes, strainer sections, couplings, lumber, hardware or other material or supplies which contractor furnishes beyond the requirements of the station when completed shall belong to the contractor, and shall be promptly removed by him, and the Board will not in any case be responsible for them. No refuse or scraps shall be left upon the site, but each contractor shall "clean up" when his work is done. Each and every provision of the irrigation law of 1895 applicable is made a part of these specifications. The Board reserves the right to stop the work and discharge the contractor at any stage, and pay for the work done at contract rate. The above general specifications apply to every contract let by the Board.

PROPOSAL.

The undersigned proposes and agrees to furnish in place at Station Number ....., located on section ....., town ....., range ....., ... county, Kansas, the following portions of the equipment, or either any or all of the portions itemized below, at the prices named; to be furnished and erected in accordance with the specifications of the Board (and the further specifications hereto attached by the undersigned) and made a part hereof:

1. WELL. Excavating well and putting casing in place, recording depth of strata, boxing and shipping samples, per foot of depth.. $——
   Extra price per foot of distance which well may go (if any) through solid rock, the Board to be the exclusive judge as to what is and what is not solid rock..... $——
2. PUMP. Pump, cylinder, strainer, valves and connections complete, T spout, flume, pit, and all necessary details..... $——
   Standard wrought-iron, lap-welded casing with couplings, per foot of length ..... $——
3. POWER. Windmill, tower, anchorages, plunger-rod and connections down to the top of the stand-pipe..... $——
   Gasoline engine with foundation, tanks, pipes, belting and all other essentials to a proper operation of the pump..... $——
4. RESERVOIR, with boxes, etc., complete..... $——
   Carting in clay, loam, or soil, if so ordered..... $——

Signature: ———. Address: ———.

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BOND.

Know all men by these presents, that we ..... of ..... Kansas, as principal , and ..... of ..... Kansas, ... of .....Kansas, ... of ..... Kansas, as sureties, are held and firmly bound unto the state of Kansas, in the penal sum of ..... dollars, lawful money of the United States, to the payment of which, well and truly to be made, we bind ourselves, our heirs, executors, administrators and assigns, jointly and severally firmly by these presents.

Whereas, the above bounden ..... was, on the .... day of ....., 189.., duly awarded by the State Board of Irrigation a contract for furnishing in place ..... at pumping station No... in ..... county, Kansas,

Now, therefore, the condition of the above obligation is such that, if the said ..... shall well, faithfully and fully perform his contract, and comply with the specifications thereto attached, then this obligation shall be void and of no effect; otherwise to be and remain in full force.

Witness our hands this .... day of ..... 189... .....
.....
.....
.....

State of Kansas, ... county, ss. Be it remembered that on this .... day of ....., 189.., before me, a notary public in and for the said county and state, personally appeared ..... and ..... who are personally known to me to be the same persons who executed the foregoing instrument, and duly acknowledge the execution of the same.

In witness whereof I have hereunto set my hand and affixed my official seal, this ..... day of ..... 189... ..... Notary Public.

State of Kansas, ... county, ss. ....., ..., and ..... being duly and solemnly sworn, does each for himself depose and say, that he is a resident of the said county and state, and is worth the sum of ..... ($.....) dollars, over and above all debts, liabilities and exemptions. So help me God. .....
.....
.....

Subscribed and sworn to before me this ..... day of ....., 189...
..... Notary Public.

ADVERTISEMENT FOR BIDS.

When a location was agreed upon notice was published in the official paper of the county where the station was to be erected. The following is a sample:

[First Publication Saturday, April 6, 1895.]

SEALED PROPOSALS.

Sealed proposals will be received by the State Board of Irrigation on and prior to the 7th day of May, 1895, for the construction of a pumping station to consist of: 1st, well; 2d, power and pump; 3d, reservoir; all to be located in township 11 south, range 32 west 6th Principal Meridian, within two miles of the city of Oakley, in Logan county, Kansas.

Specifications for the above work as a whole and in divisions may be had on application to the Secretary of the Board at Russell, Kansas, or at the office of the Board in the Capitol at Topeka. WM. B. SUTTON, *Secretary.*

The Secretary kept a mailing list of the names and post-office address of all persons inquiring about this work, and a copy of the notice as above was sent to each one of them.

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A copy of specifications, including proposal blanks, bond and envelope for inclosing bid was sent to every inquirer.

At the first meeting of the Board after the expiration of the time limited, the Board opened the bids, tabulated them, heard all persons requesting a hearing and awarded the contracts.

Curiosity was great in reference to the first stations, and more than 100 sets of specifications were called for, and numerous bids submitted. Later on as the requirements of the specifications became better known, bidders were fewer, and it was with great difficulty that responsible parties were found to undertake the work at reasonable figures.

HISTORY AND DESCRIPTION OF THE STATIONS.

Here is given a tabulated statement of the wells sunk and stations erected, with their locations and a condensed description of their equipments:

No.	County.	Depth of well, feet.	Depth to water, feet.	Lowest stratum reached.	Pump used.	Power used.
1..	Hamilton...	196	170	Soapstone	Cook cylinder, 5½ x 42 inches.....	16-foot steel b.g.Ideal windmill.
2..	Gray.....	61	42	Sand and gravel..	Frizell tubular 8-inch cylinder.....	Crane irrigator, 14-foot steel b. g.
3..	Grant.....	231	123	Black shale.....	Woodmanse butterfly valve, 5½x8 feet.	14-foot Mogul, steel b. g. windmill.
4..	Sherman....	166	127½	Gravel	Cook, 5½ x 60 inches,	25-foot Eclipse, solid wooden wheel.
5..	Logan.....	162	93	Rock	Cook, 7¼ x 60 inches,	10-horse power Fairbanks, Morse & Co. gasoline engine.
6..	Wichita	163½	74½	Shale	Woodmanse butterfly, 5½ x 8 feet.....	14-foot steel b.g.Ideal windmill.
	"	145	75	Soapstone.....	Cook, 5½ x 42 inches,	16-foot steel b.g.Ideal windmill.
7..	Greeley.....	70	.....	Shale.....	.....	.....
8..	Lane..	89	52	Shale.....	Woodmanse butterfly valve, 5½ x 8 feet,	14-foot Mogul, b. g. steel windmill.
9..	Haskell.....	291	202	.....	Cook, 5½ x 42.....	25-foot Halladay standard sectional wood windmill.
10..	Trego.....	110	.....	Shale.....	.....	.....
11..	Rawlins....	213	188	Soapstone.....	Cook, 4½ x 42.....	16- foot b. g. Ideal.
12..	Rooks.	59⅝	34	Black shale.....	Frizell tubular, 5 x 30	14-foot Crane irrigator, b. g. steel.
13..	Ford.....	192½	122	Gravel.....	Frizell tubular, 5¾ x 30 inches.....	16-foot Ideal, b. g. steel windmill.
14..	Seward.....	172	109	Shale.....	Cook, 5½ x 42...	16-foot b.g.steel Fairbanks, Morse & Co. windmill.
15..	Sheridan ...	.....	.....	.....	.....	.....
16..	Hodgeman..	277	128	Blue clay.....	Frizell tubular, 5¾ x 30.....	Fairbanks, Morse & Co., b. g. 16-foot steel windmill.
17..	Trego.....	116	....	Shale..	....	.....
18..	Greeley	113	96	Shale.....	....	.....
19..	Wallace	44	32½	Shale..	5½ x 40 Fairbanks, Morse & Co..	12-foot Fairbanks, Morse & Co., steel b. g. windmill.

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The following is a more extended history and description of each station, beginning at

STATION No. 1. HAMILTON COUNTY.

This station was located upon recommendation of Mr. Frost upon unoccupied school-lands, section 36, township 23, range 39. Hamilton county.

On May 1st, 1895, the contracts for its construction were let, due publication having been made for thirty days in the official paper of Hamilton County, and copies of the specifications sent out to all applicants. The contract for the well was let to J. C. Lupton, Syracuse, Kas. The pump and casing to the United States Water and Steam Supply Company, of Kansas City, Mo. The power, windmill and tower, to the Stover Manufacturing Company, Freeport, Ill. The reservoir to F. M. Kelley, Kendall, Kas.

This is a tubular well and when completed was 196 feet deep; diameter, 6 inches; depth to water, 170 feet, and reached lowest water bearing stratum above shale.

The pump a Cook cylinder 5½ in. x 42 in., furnished with Cook sand screen No. 10, 5½ in. x 16 ft.

The power, a 16-foot steel, back-geared Ideal windmill upon a 40-foot steel tower.

The reservoir 80x125 feet; embankments outside 4 feet, inside 5½ feet.

The cost of this plant was $869.12, and there has been expended upon it in repairs, $25.80.

The supply of water was good and sufficient for the pump with the power employed. The stroke of the mill is 16 inches. Size of cylinder, 5½x42 inches. Maximum capacity of each stroke, 1.64 gallons. Maximum capacity per minute at 20 strokes, 32.8 gallons. Maximum capacity per hour, reckoning efficiency of pump at 75 per cent., 1,476 gallons.

The great storm of April 28, 1896, blew over the mill and tower and completely wrecked both. The contractors, the Stover Manufacturing Company, of Freeport, Ill., were immediately notified, and requested to replace them. They still neglect and refuse to comply.

RECORD OF STRATA passed through in sinking well at station No. 1, southeast quarter of northeast quarter of section 36, township 23, range 39 west, sixth principal meridian, Hamilton county, Kansas.

Stratum and sample number.	Depth (in feet) from surface to—		Thickness (in feet) of stratum.	Distance, top of ground to first water, feet.	Exact distance, top of ground to top of water when finished, feet.	Characteristics: Color, hardness, popular names, whether dry or water-bearing.
	Top of stratum.	Bottom of stratum.				
1	.....	1½	1½	.....	.....	Top soil.
2	1½	8	6½	.....	.....	Light subsoil.
3	8	14	6	.....	.....	Gypsum.
4	14	71	57	.....	.....	Sand and gravel.
5	71	99	28	.....	.....	Solid rock.
6	99	105	6	.....	.....	Sand and gravel.
7	105	110	5	.....	.....	Red gypsum.
8	110	130	20	.....	.....	Sandy clay.
9	130	142	12	.....	.....	Gravel and boulders.
10	142	155	13	.....	.....	Fine yellow sand.
11	155	164	9	.....	.....	Gravel.
12	164	170	6	.....	.....	Clay.
13	170	180	10	.....	.....	Water, sand and gravel.
14	180	187	7	.....	.....	Water gravel.
15	187	192	5	.....	.....	Fine sand at bottom of water stratum.
16	192	196	4	.....	.....	Yellow shale or soapstone.

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On May 15, 1896, the following petition, signed by 155 citizens of Hamilton and Kearney counties was presented to the Board:

"To the Honorable State Board of Irrigation: From the fact that the windmill at the state pumping plant situated in Hamilton county has blown down and is destroyed and it is understood that your honorable Board contemplates the erection of another windmill, we the undersigned citizens of Hamilton and Kearney counties respectfully petition your honorable Board, that the money necessary for the erection of a new mill and as much more as the Board may see fit to appropriate be expended in sinking the present well deeper, and demonstrating at what depth artesian water can be obtained."

The Board came to the conclusion that work then under way and to which the Board was committed, would so nearly absorb the funds on hand, that it was not justified in complying with the prayer of the petition.

STATION No. 2. GRAY COUNTY.

Located upon the recommendation of Mr. Frost upon unoccupied school-lands. S.E. ¼ of S.W. ¼, Sec. 16, T. 26, R. 28, Gray county.

After due publication for sealed proposals for 30 days in the official paper of Gray county, and the sending out of the specifications to all inquirers, the contract was let as follows, on May 1, 1895:

Well, pump, power and reservoir to Crane & Co., Kansas City, Mo., and cost completed $789.87. This well was dug and walled with brick 4 feet in diameter, depth, 61 feet; depth to water 42 feet.

The power used is a 14 foot steel, back geared windmill; named the "Crane Irrigator," erected upon a 40-foot steel tower.

The reservoir is 80 x 125 feet; embankment, 4 feet outside and 5½ feet inside.

On account of the sandy soil in which the reservoir was constructed about 50 wagon loads of clay were carted and thoroughly puddled into the bottom and sides before it would hold water.

The pump is a Frizell tubular cylinder 8 inches in diameter.

The supply of water at this station is abundant.

Present condition is good, and reservoir holds water fairly well considering the material of which it is composed.

The storm of April 28, 1896, blew the mill off the tower. The contractors promptly repaired it without charge.

A drawing showing the details of its construction is given. See Fig. 1.

RECORD OF STRATA passed through in sinking well at Station No. 2, southeast quarter of southwest quarter of section 16, township 26, range 28 west, sixth principal meridian, Gray county, Kansas.

Stratum and sample number.	Depth (in feet) from surface to—		Thickness (in feet) of stratum.	Distance, top of ground to first water, feet.	Exact distance, top of ground to top of water when well finished, feet.	Characteristics: Color, hardness, popular names, whether dry or water-bearing.
	Top of stratum.	Bottom of stratum.				
1	.....	3	3	42	42	Very sandy.
2	3	17	14	.....	.....	Sand.
3	17	19	2	.....	.....	Clay.
4	19	23½	4½	.....	.....	Sand.
5	23½	26½	3	.....	.....	Clay.
6	26½	29	2½	.....	.....	Clay.
7	29	30½	1½	.....	.....	Sand and gravel.
8	30½	38½	8	.....	.....	Sand.
9	38½	41	2½	.....	.....	Clay and gravel.
10	41	61	20	.....	.....	Water-bearing sand and gravel.

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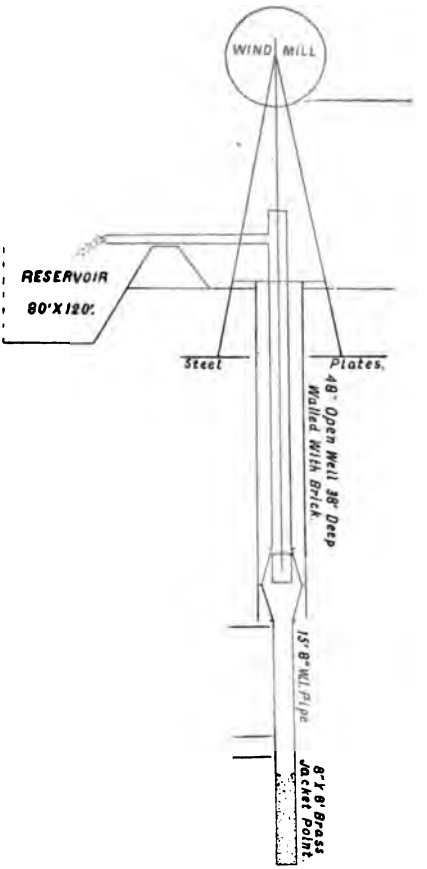

Fig. 1.

Station No. 2, Gray county. (Cimarron.)

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STATION No. 3. GRANT COUNTY.

Located upon the recommendation of Mr. Frost upon unoccupied school-lands, N.W. ½ of N.W. ¼ of Sec. 36, T. 29, R. 37, Grant county.

After due publication for sealed proposals, and distribution of specifications the contracts for this station were let as follows, on May 1, 1895:

Well, to Wm. Morrison, Shockeyville, Kas. Pump, casing and power to the Woodmanse & Hewitt Mfg. Co., Freeport, Ill. Reservoir, to Jerry Brolier, Ulysses, Kas.

The cost of this plant completed, was $937.91; repairs on same, $126.04; operating, $8.

The total depth of the well is 231 ft.; depth to water, 123 ft. This well reaches the shale floor on which rests the tertiary formation, containing the western underflow.

The power used is a 14-ft. steel, back geared mill, called "The Mogul," manufactured by the contractors.

The pump is the butterfly valve pattern, 5½ inches in diameter.

Reservoir, 80x125 feet; height of walls outside, 4 feet; inside, 5½ feet.

The supply of water at this plant is abundant.

Present condition of the plant is good.

The storm of April 28, 1896, blew the mill off the tower, but it was promptly replaced with a new one by the Woodmanse & Hewitt Manufacturing Co., the contractors, without charge.

RECORD OF STRATA passed through in sinking well at station No. 3, northwest quarter of north west quarter of section 36, township 29, range 37 west, sixth principal meridian, Grant county, Kansas.

Stratum and sample number.	Depth (in feet) from surface to—		Thickness (in feet) of stratum.	Distance, top of ground to first water.	Exact distance, top of ground to top of water when well finished.	Characteristics: Color, hardness, popular names, whether dry or water-bearing.
	Top of stratum.	Bottom of stratum.				
1	.....	2	2	123	123	Top soil.
2	2	8	6	.....	.....	Clay and gypsum.
3	8	16	8	.....	.....	Ashy.
4	16	21	5	.....	.....	Red sand, hard.
5	21	35	14	.....	.....	Gypsum, very hard.
6	35	70	35	.....	.....	Red sand.
7	70	79	9	.....	.....	Clay and gypsum, very hard.
8	79	91	12	.....	.....	Red sand, hard.
9	91	93	2	.....	.....	Gray sand, soft.
10	93	100	7	.....	.....	Red sand, hard.
11	100	109	9	.....	.....	Red sand, soft.
12	109	120	11	.....	.....	Sandy clay, hard.
13	120	124	4	.....	.....	Clay.
14	124	144	20	.....	.....	Joint clay, water-bearing.
15	144	148	4	.....	.....	Hard red clay, dry.
16	148	153	5	.....	.....	Red sand, water-bearing.
17	153	154	1	.....	.....	Hard red clay, dry.
18	154	157	3	.....	.....	Gypsum, hard, dry.
19	157	165	8	.....	.....	Sand, water-bearing.
20	165	170	5	.....	.....	Joint clay, water-bearing.
21	170	172½	2½	.....	.....	Coarse sand, water-bearing.
22	172½	185	12½	.....	.....	Red clay, dry.
23	185	199	14	.....	.....	Sand, water-bearing.
24	199	202	3	.....	.....	Joint clay, water-bearing.
25	202	212	10	.....	.....	Sand, water-bearing.
26	212	220	8	.....	.....	Rock, dry.
27	220	231	11	.....	.....	Blue shale, dry.

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This well was drilled and 8-inch artesian well casing was sunk 211 feet; inside of this was suspended 185 feet of 6-inch pipe and the cylinder, below which was 24 feet of 4-inch pipe, 8 feet of which was perforated. After the mill was put to work the sand and mud filled up the well 27 feet, and the pump pipe 36 feet. The pump was then taken out, 55 feet of No. 20 galvanized iron casing was dropped inside of the 8-inch artesian well casing; this galvanized iron casing was 7 inches in diameter and was perforated from the inside with a cold chisel, about 72 perforations to the lineal foot. The artesian well casing was then drawn up nearly to the top of the galvanized iron casing. The pump was then replaced on 155 feet of 6-inch pipe, having below the cylinder 16 feet of 4-inch pipe and 8 feet of 4-inch sand-screen. This worked well. When the mill was repaired in 1896 a stronger pump was substituted for the old one by the contractor, at his own expense.

In this locality floating sand cuts out leathers on plungers very fast. We know no remedy for it except continuous pumping until the sand is exhausted. It is so fine that to entirely exclude it from the pump would materially lessen the supply of water.

STATION No. 4. SHERMAN COUNTY.

Located upon S.E. ¼ of the S.E. ¼ of Sec. 16, T. 8, R. 38, Sherman county, which site was held under contract with the state by Mr. M. B. Tomblin and by him released to the state.

After due publication and distribution of specifications the contracts for this station were on May 1, 1895, let to Fairbanks, Morse & Co. of Kansas City, Mo.

The cost of this plant complete was $2,078.23; repairs, $68.35; cost of experiments, $231.11; operating expenses, $101.52.

This station consisted of a 6-inch tubular well; total depth 166 feet, depth to water 127½ feet.

A 10-horse power Fairbanks, Morse & Co. gasoline engine, and reservoir 80 × 125 feet.

The power was applied to the pump by a walking beam, which is an awkward contrivance. The pump had a cylinder 5½ inches in diameter and 60 inches in length. The stroke used was 28 inches.

There is also an engine house erected on this plant.

The test of this well being very satisfactory, and believing the engine had power to operate a larger pump, the Board tranferred the engine to station No. 5, at Oakley, Logan county, and substituted in its place a 25-foot wooden wheel called the "Eclipse," manufactured by Fairbanks, Morse & Co., at an expense of $400, which was ready for operation in February, 1896, and has since that time been doing excellent service. The apparent large cost of this station is due to the fact that it is charged with the gasoline engine and the windmill.

A series of experiments were conducted at this station under the immediate supervision of Mr. W. G. Russell, civil engineer, in the employ of the Board. His report is as follows:

Upon Water Supply, Evaporation and Seepage.

"Hon. Wm. B. Sutton, Secretary State Board of Irrigation, Russell, Kas.:

"Dear Sir — I beg to submit a report of the work done, and experiments made, at the state well at Goodland, Sherman county, Kansas, in obedience to your request.

"I went to Goodland on the 12th day of September, 1895, made an examina-

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tion of the plant and ordered the necessary apparatus made for conducting the experiments.

"These experiments were made for the purpose of determining the amount of water furnished by the well, the capacity of the engine and pump, and loss of water from evaporation, seepage, etc. The well is located one and a half miles east of Goodland, and is six inches in diameter and 166 feet deep, and the pumping is done by a gasoline engine with a pump having a cylinder five and one-half inches in diameter and 36-inch maximum stroke. I returned to Goodland the 24th and completed the measuring apparatus, and had everything in operation the morning of the 26th. The evaporating pan and floats are of galvanized iron, and of size and shape used by the United States Geological Survey, and the reading scale and rod were furnished by Mr. F. H. Newell, chief hydrographer of that survey, Washington, D. C. This pan was placed near the center of the reservoir, and so anchored that it would rise and fall with the water therein.

"It is necessary in this country especially that this should be as far from land as possible in order to keep dirt from settling in the pan, and temperature the same as the body of the water. I constructed a runway for the observer extending from the top of the reservoir embankment out to the pan and made the first 12 feet removable so that the observer could take it into the engine house and thus prevent interference by outsiders. To put into operation, the pan is filled until only a few inches is above water, and when quiet a very careful reading is taken from the guage and recorded, and also the time of day and the temperature of the water, both inside and outside of the pan. The following table gives results of measurements made, beginning September 26 and ending October 24, 1895:

Date.	Time. A. M.	Scale height.	Diff.	Inside temperature.	Outside temperature.	Reading after filling.	Water at well.
Sept. 26	7:30	1.40 in.	.....	56 deg.	58 deg.	.....	56 deg.
27	7:30	1.55 "	.15 in.	62 "	64 "	.....	.....
28	7:25	1.75 "	.20 "	54 "	55 "	.....	.....
30	7:50	2.05 "	.30 "	54 "	56 "	.....	.....
Oct. 1	7:30	2.30 "	.25 "	57 "	56 "	.....	.....
2	7:10	2.55 "	.25 "	62 "	60 "	.....	.....
3	7:10	2.75 "	.20 "	58 "	58 "	.....	.....
4	7:05	2.95 "	.20 "	58 "	59 "	.....	.....
5	7:40	3.00 "	.05 "	56 "	55 "	.....	.....
7	7:30	3.25 "	.25 "	57 "	56 "	1.35 in.	.....
8	10:00	1.55 "	.20 "	56 "	56 "	.....	.....
9	7:10	1.70 "	.15 "	60 "	58 "	.....	.....
10	7:55	1.90 "	.20 "	57 "	56 "	.....	.....
11	7:20	2.10 "	.20 "	56 "	54 "	.....	.....
12	7:05	2.30 "	.20 "	57 "	56 "	.....	.....
14	7:20	2.70 "	.40 "	56 "	55 "	.....	.....
15	7:20	2.90 "	.20 "	57 "	56 "	.....	.....
16	7:40	3.10 "	.20 "	56 "	54 "	.....	.....
18	7:30	3.50 "	.40 "	52 "	53 "	1.40 in.	.....
19	7:30	1.60 "	.20 "	48 "	49 "	.....	.....
21	7:40	1.95 "	.35 "	51 "	50 "	.....	.....
22	7:20	2.15 "	.20 "	48 "	48 "	.....	.....
23	7:35	2.30 "	.15 "	45 "	46 "	.....	.....
24	7:30	2.45 "	.15 "	47 "	46 "	.....	.....
28 days			5.05 in.				

"This shows an average evaporation of .18 of an inch for each day from September 26 to October 24, in all 28 days, and would give 5.41 inches for 30 days. I would suggest that if your board has the means to do so, it continue this measurement as this is a very large factor of the loss that must be taken into account in estimating amounts of water furnished from reservoirs, and as we have very little information on this subject for this section of the country.

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"I put up the meter furnished your board by the National Meter Co., of Chicago, to measure the quantity of water pumped from the well, but found it entirely inadequate, being capable of passing only about one-half or two-thirds of that quantity under that head.

"This meter has not sufficient capacity unless put under pressure, or a much greater head; either of which reduces the capacity of the engine. I had it packed ready for shipment, and left in charge of Mr. M. B. Tomblin, a member of your Board, at Goodland.

"I constructed an accurate gage, reading direct to the .01 of a foot, and by estimation easily one-half of this, and placed it in the reservoir perpendicular and immovable by any ordinary force, and accessible from the runway to the evaporating pan.

"The height of water on this gage was read each morning before starting the pump, and each evening after the pump was stopped.

"I made a careful measurement of the capacity of the reservoir by setting tops of stakes at the same elevation at each foot of height with a Wye level, and then measuring the area within each set, and the slopes of the embankments, being practically uniform, I used each two adjacent elevations as a basis for intermediate measurements. All measurements of quantity of water pumped are based on these measurements of the reservoir, as the meter intended for this purpose failed. The engine registered the number of revolutions made, and indicated 269,911 revolutions in 208¼ hours actual running time, which is equal to 1,296.6 per hour or 21.61 revolutions per minute. By actual count with a stop watch I found it about 21.7 for a short time.

"This engine pumped 787,600 gallons of water in 208¼ hours actual running time, or 3,783.5 gallons per hour, or 2.92 gallons per stroke. The speed of this engine might likely be increased to give 4,500 gallons on that foundation, and the cylinder might be packed to give greater efficiency. A careful estimate was made of the loss of water from evaporation and seepage, and both amounts added to the gage readings, so that the amounts given are intended to include all the water pumped.

"The water in this well is of a most excellent quality, and from all indications is inexhaustible. At no time was there any indication of exhausting the supply.

"The water pumped from this well as measured would cover 504 square feet of land, one foot deep in one hour; 12,107 square feet or more than ¼ of one acre one foot deep in 24 hours: 8.4 acres one foot deep in one month; and 101.5 acres one foot deep in 365 days. If only three inches are used for each irrigation then these figures in each case can be multiplied by four.

"There was no cost for repairs to the engine during the entire run; the lubricating oil cost one dollar, and there were 265 gallons of gasoline used for the entire run, or 1.23 gallons per hour.

"Respectfuily submitted. W. G. Russell."

The reservoir at this station holds water almost perfectly, and it has stood full nearly all the time since its construction.

The plant was leased to Wm. Umbarger, who cultivated it quite successfully in 1895 and 1896.

Reference to the strata record which follows shows that this pump draws all its water from a single stratum of coarse gravel 8 feet thick. Where such exists the most economical well is the tubular.

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RECORD OF STRATA passed through in sinking well at station No. 4, southeast quarter of south east quarter of section 16, township 8, range 39 west, sixth principal meridian, Sherman county, Kansas.

Stratum and sample number.	Depth (in feet) from surface to—		Thickness (in feet) of stratum.	Distance, top of ground to first water.	Exact distance, top of ground to top of water when well finished.	Characteristics: Color, hardness, popular names, whether dry or water-bearing.
	Top of stratum.	Bottom of stratum.				
1	.....	2	2	127½	127½	Black soil.
2	2	18	16	.....	.....	White soil.
3	18	31	13	.....	.....	Red clay.
4	31	37	6	.....	.....	Magnesia.
5	37	43½	6½	.....	.....	Hard rock.
6	43½	62½	19	.....	.....	Dry sand.
7	62½	76½	12	.....	.....	Red clay.
8	76½	83½	7	.....	.....	Hard rock.
9	83½	99	15½	.....	.....	Sand and rock.
10	99	103	4	.....	.....	Magnesia.
11	103	109	6	.....	.....	Red sand and rock.
12	109	113½	4½	.....	.....	Hard rock.
13	113½	127½	14	.....	.....	Red clay.
14	127½	135	7½	.....	.....	Water sand.
15	135	158	23	.....	.....	Magnesia clay.
16	158	166	8	.....	.....	Water gravel.

STATION NO. 5. LOGAN COUNTY.

Located on the west half of the northwest quarter section 3, township 11, range 32, Logan county, upon the recommendation of Mr. Sutton.

This location consists of 40 acres of land adjoining the city of Oakley, and was conveyed to the state of Kansas by deed dated September 25, 1895, and executed by H. F. Giessler and Kate P., his wife, to the state of Kansas, and recorded in the office of the register of deeds, Logan county, in deed book No. 5, p. 467.

After due publication and distribution of specifications the contracts were let for this plant as follows: Well, to W. S. Gorrell. Reservoir, to J. W. Kerns. Pump, power, tubing, etc., to Fairbanks, Morse & Co.

This plant consists of an 8-inch well; Cook cylinder, 7½ inches in diameter; a 10-horse power gasoline engine manufactured by Fairbanks, Morse & Co.; and engine house and reservoir.

The engine is the same that was located at Station No. 4, Sherman county, and was erected by Fairbanks, Morse & Co.

The cost of this plant completed was, $1,503.60; repairs, $231.30; experiments and operation, $218.70.

The original depth of this well was 162 feet; depth to water 93 feet; the well was cased with perforated galvanized iron, 10 inches in diameter, to a depth of 140 feet.

The pump and pipe were suspended inside of this casing.

The yield of the well was quite satisfactory.

A figure showing the pipe and pump in the well is given. See Fig. 2.

The reservoir held water from the first. The banks were well puddled when constructed, and were protected from washing on the inside by nailing fence boards together 6 inches apart extending around the entire inner surface of the embankments, three abreast and floating on the water.

A counter was put upon the walking beam of the engine by which every stroke of the pump was recorded.

An evaporation pan was placed in the reservoir, also a graduated stake for reading the height of the water in the reservoir. A No. 3 Nash water meter furnished by the National Meter Co. was fixed to the discharge pipe for measuring the water raised.

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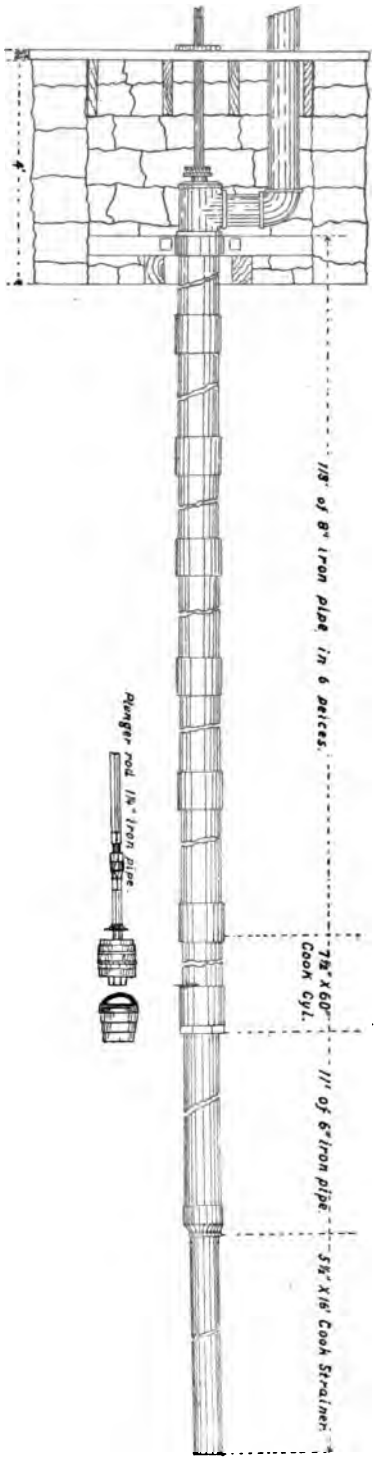

Fig. 2.

Pipe and Pump. Station No. 5, Logan county. (Oakley.)

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A telltale consisting of a galvanized iron float properly loaded was placed in another well distant 66.4 feet from the one in which the pump was located. This float was connected by a copper wire to a light chain running over a pulley affixed to the upper edge of a 16-foot length of one inch pipe, the lower end of which was imbedded in a large stone immediately over the well.

To the end of the chain was affixed a square-edged marker and the pipe was graduated so when the water in the well stood at its normal height the marker indicated 0; as the water fell in the well the float sank with it and drew the marker up the pipe thus indicating the rise and fall of the water in the second or test well.

Careful observations were made of this test at stopping and starting of the engine.

A combination of observations and experiments at this station is here given.

Date, 1896.	Engine.					
	Time of starting.	Time of stopping.	Time lost.	Actual running time.	Number of strokes of pump.	Cubic ft. (theoretic quantity) of water pumped.
May 13	7.10	6.12	0.25	10.33	11,259	7,691
" 14	7.00 a. m.	5.30 p. m.	1.10	9.20	9,649	6,643
" 14	6.25 p. m.	2.25 a. m.	4.00	4.00	4,283	2,951
" 15	8.05 a. m.	5.30 p. m.	1.15	8.10	8,927	6,151
" 15	6.40 a. m.	6.15 p. m.	0.10	11.25	12,658	8,589
" 16	6.25 p. m.	5.30 p. m.	1.10	9.55	10,305	7,100
" 16	6.30 p. m.	5.00 a. m.	1.15	9.15	10,807	7,446
" 17	8.45 a. m.	6.15 p. m.	1.10	8.20	7,542	5,196
" 17	6.20 p. m.	1.50 a. m.	1.40	5.50	6,305	4,344
June 9	7.50 a. m.	5.30 p. m.	.....	9.40	10,000	6,890
" 10	6.15	5.45	1.20	10.10	10,510	7,241
" 11	7.00	6.00	1.00	10.00	10,147	6,991
" 12	6.10	7.10	1.00	12.00	12,459	8,584
" 13	6.15	7.30	7.30	5.45	5,981	4,120
" 15	6.15	7.30	9.00	4.15	4,736	3,064
" 16	6.00	7.30	1.20	12.10	13,069	9,004
" 17	5.50	7.30	1.35	12.05	12,984	8,943
" 18	6.00	6.30	1.30	11.00	11,892	8,293
" 19	6.00	7.30	1.10	12.20	13,011	8,964
" 20	6.30	7.30	2.00	11.00	11,659	8,033
" 22	6.15	7.30	1.30	11.45	12,382	8,531
" 23	7.15	6.00	1.30	9.15	10,266	6,973
" 24	8.00	6.00	2.00	8.00	7,417	5,510
" 25	6.45	6.00	1.10	10.05	11,289	7,778
" 26	6.45	6.00	1.10	10.05	11,969	8,226
" 27	6.45	6.00	1.00	10.15	11,488	7,915
" 29	6.45	5.00	0.20	9.55	11,582	7,979
July 1	6.20	5.30	1.10	10.00	11,179	7,702
" 2	6.10	5.30	1.00	10.20	11,977	8,252
" 3	9.30	6.00	3.00	5.30	5,893	3,760
" 6	7.00	4.35	1.00	8.35	9,793	6,747
" 8	12.45	5.30	0.10	4.35	5,320	3,665
" 9	6.55	4.30	1.30	8.05	8,988	6,192
" 10	7.15	12.00 noon	3.00	1.45	4,046	2,789
August 4	9.05	7.45	1.45	8.55	9,783	6,740
" 5	6.40	10.10	.....	3.30	3,875	2,669
" 7	1.30 p. m.	6.20 a. m.	1.00	15.50	18,086	12,326
" 8	6.30 a. m.	5.00 p. m.	1.00	9.30	10,871	7,490
" 24	7.15	6.40	1.20	10.05	11,573	7,974
" 25	6.00	6.30	1.15	11.15	11,389	7,487
" 26	6.00	6.35	1.20	11.15	10,770	7,320
" 27	5.40	5.30	5.00	6.50	5,950	4,099
" 28	6.00	5.20	1.00	10.00	11,037	7,604
" 29	6.15	12.00 noon	0.20	5.25	5,765	3,972
" 31	3.00	5.40	0.10	2.30	3,038	2,093
September 1	8.30	5.30	0.15	8.45	10,428	7,184
" 2	6.00	1.00 p. m.	1.00	6.00	4,811	3,314
Total	.....	.....	.....	415.13	.....	.....

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Date, 1896.	Water-meter.		Reservoir.			
			Morning.		Evening.	
	Cubic feet of water.	Per cent. of efficiency.	Time.	Height.	Time.	Height.
May 13	6,896	89.6	7.10	2-4	6.12	2-11
" 14	6,850	103.0	7.00	2-11	5.30	3-4½
" 14	1,600	54.3	6.25	3-4½	3.25	3-7
" 15	6,197	100.7	8.05	3-6	5.30	3-10½
" 15	7,433	86.5	6.40	3-10¼	6.15	4-4½
" 16	5,794	81.6	6.25	4-4½	5.30	4-9
" 16	4,895	65.7	6.30	4-9	5.00	5-0
" 17	5,100	98.0	8.45	4-11½	6.15	5-1
" 17	2,390	55.0	6.20	5-1	1.50	5-3
June 9	6,680	96.9	7.50	1-5	5.30	1-11¾
" 10	4,970	68.0	6.15	1-11¼	5.45	2-6
" 11	5,630	80.0	7.00	2-6	6.00	3-0
" 12	6,870	80.0	6.10	2-11¾	7.10	3-6
" 13	3,330	80.0	6.15	3-5¼	7.30	3-7
" 15	2,550	83.0	6.15	3-3¼	7.30	3-5¼
" 16	6,820	75.0	6.00	3-8	7.30	3-11
" 17	7,070	79.0	5.50	3-10¼	7.30	4-3¼
" 18	6,470	78.0	6.00	4-2¼	6.30	4-7¾
" 19	7,060	79.0	6.00	4-6¾	7.30	5-0
" 20	6,595	82.0	6.30	4-10½	7.30	5-3
" 22	6,845	80.0	6.15	4-10	7.30	5-2½
" 23	5,514	80.0	7.15	5-0	6.00	5-4½
" 24	3,276	64.0	8.00	5-2	6.00	5-5
" 25	5,800	76.0	6.45	5-3	6.00	5-7½
" 26	6,100	74.0	6.45	5-5¾	6.00	5-10
" 27	5,670	72.0	6.45	5-8	6.00	6-0
" 29	5,625	70.0	6.30	5-6	5.00	5-10¼
July 1	5,580	72.0	6.20	5-6	5.30	5-10¾
" 2	5,870	71.0	6.10	5-8¾	5.30	6-1
" 3	2,930	78.0	9.30	5-11¾	6.00	6-1
" 6	4,750	70.0	7.00	5-6	4.35	5-9¾
" 8	2,720	74.0	12.40	5-6	5.30	5-9¼
" 9	4,480	72.0	6.55	5-7	4.30	5-10½
" 10	1,975	71.0	7.15	5-7	12.00	5-9½
August 4	4,855	72.0	9.05	2-0	7.45	2-6
" 5	2,030	75.0	6.40	2-6	10.40	2-8
" 7	9,085	73.0	1.30	2-7½	6.20	3-5
" 8	5,475	73.0	6.30	3-5	5.00	3-11
" 24	5,760	72.0	7.15	2-5	6.40	2-11
" 25	5,480	70.0	6.00	2-10¾	5.35	3-5
" 26	5,530	75.0	6.00	3-4¼	5.35	3-10¾
" 27	2,870	70.0	5.40	3-10½	5.30	3-11¼
" 28	5,300	69.0	6.00	3-11	5.20	4-4
" 29	2,640	70.0	6.15	4-3	12.00	4-6¾
" 31	1,620	77.0	3.00	4-1½	5.40	4-3
September 1	5,290	73.0	8.30	4-2¾	5.30	4-7¾
" 2	.....	.....	6.00	4-7	1.00	4-9
Total	134,270	.....	.....	.....	.....	.....

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Date, 1896.	Moisture, rain.	Gasoline, Amount used in gallons.	Telltale in well 64.4 feet distant.	
			Height at starting.	Height at stopping.
May 13		9.35		9
" 14		8.30	7	9
" 14		3.56	8	9
" 15		6.38	7	12
" 15		10.31	7	12
" 16		7.90	11⅛	13
" 16		7.34	7	12
" 17		7.41	7	12⅛
" 17		5.91	12	13
June 9		8.60		5
" 10	¼ inch.	9.04	2	8
" 11		8.90	3	9
" 12		10.68	4	9
" 13		5.56	5	8
" 15		4.56	3	4
" 16		12.97	3	10
" 17		11.81	5	10
" 18	1 inch.	13.24	4	10
" 19	1/10 "	11.81	4⅛	11⅛
" 20		12.50	5⅛	11⅜
" 22	½ inch.	9.93	3	11
" 23	¼ "	8.86	6	10
" 24	1/10 "	8.59	5	9
" 25	Heavy mist.	10.93	4	12⅛
" 26		10.89	4½	12
" 27		10.89	6	12
" 29		10.99	3	9
July 1		10.62	3	9
" 2	Sprinkle.	11.37	4	10
" 3		5.30	4	8
" 6		8.81	1	6
" 8		4.78	1	7
" 9		8.08	3	10
" 10		3.70	4	
August 4		7.50		6
" 5		3.00	3	4
" 7		13.50		10
" 8		10.00	10	12
" 24		9.50		4½
" 25		9.00	½	6½
" 26		8.50	2	6½
" 27		4.75	2	3
" 28		9.00	1½	6½
" 29		3.75	2	4
" 31		1.75		2
September 1		8.50		6½
" 2			1	
Totals	2⅛ inches.	388.62		

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EVAPORATION TABLE—1896.

June.			July.			August.			September.			October.		
Date.	Evaporation.	Amount of rainfall.	Date.	Evaporation.	Amount of rainfall.	Date.	Evaporation.	Amount of rainfall.	Date.	Evaporation.	Amount of rainfall.	Date.	Evaporation.	Amount of rainfall.
4			1	*4		1	*6		1	*6		1	*3	
6		Sprinkle.	2	11		2	5		2	3		2	2	
11		¼ inch.	3	6	1/16 inch.	3	8		3	4		3	4	
14		Sprinkle.	4	3		4	5		4	4		4	2	
18		¾ inch.	5	4		5	2		5	5		5	0	
20		1/16 inch.	6	3	1/16 inch.	6	5		6	5		6	2	
22		1/16 inch.	7	6		7	4		7	4		7	2	
23		½ inch.	8	5		8	5		8	3		8	3	
24		1/16 inch.	9	6		9	4		9	5	1 inch.	9	2	
25		1/16 inch.	10	6		10	9		10	1		10	2	
26		Heavy mist.	11	12		11	3	Sprinkle.	11	1		11	2	
29		Sprinkle.	12	2		12	4		12	2	1/16 inch.	12	2	
			13	8		13	5		13	0	Mist.	13	3	
			14	4		14	6		14	1	¼ inch.	14	1	
			15	3		15	7		15	1		15	2	
			16	4		16	3	Mist.	16	1		16	3	
			17	2	⅛ inch.	17	6		17	0	Heavy mist.	17	2	
			18	3	⅛ inch.	18	2	1/16 inch.	18	1	¼ inch.	18	2	
			19	3		19	2	Mist.	19	1		19	2	
			20	5		20	3		20	4		20	2	
			21	2	1 inch.	21	3	1⅛ inches	21	1	Sprinkle.	21	2	
			22	2	Sprinkle.	22	3		22	3		22	1	3/16 inch.
			23	4		23	2		23	3		23	1	1/16 inch.
			24	5		24	4		24	3		24	1	
			25	5	Sprinkle.	25	4		25	4		25	1	
			26	2	Heavy sprinkle.	26	4		26	1		26	1	
			27	7		27	5		27	2		27	1	
			28	4		28	6		28	3		28	0	2 in. rain
			29	7		29	4		29	2		29	0	and snow
			30	4	1/16 inch.	30	5		30	3		30	0	
			31	5		31	5					31	0	
Totals		2 1/16 inches		9 3/16	1 3/16 inches		8 1/16	1 3/16 inches		4 1/16	1 3/16 inches		3 3/16	2 1/16 inchs

*Expressed in sixteenths of an inch.

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Summary.

1896.	Rainfall, inches.	Evaporation, inches.
June	2.18	.....
July	1.40	$9\frac{3}{16}$
August	1.56	$8\frac{11}{16}$
September	1.56	$4\frac{13}{16}$
October	2.06	$3\frac{3}{16}$
Totals	8.76	$21\frac{7}{8}$

From this table it will appear that the pump was operated from 7 A. M., May 14, 1896, until 1:50 A. M., May 18, 1896, 91 hours 50 minutes, with stoppages amounting to 14 hours 15 minutes, leaving actual time of pumping 77 hours 35 minutes, during which time there was raised from the well, according to the meter, 40,259 cubic feet of water, or 3,724 gallons per hour, or 62 gallons per minute.

The full capacity of the pump per stroke is seven-tenths cubic foot.

The telltale in the second well registered, at the time of stopping, a fall of 13 inches, which was the lowest noted during the whole season. It was intended to continue this incessant pumping longer to make the test more severe, but a break in the engine at 1:50 A. M. of the 18th of May brought the experiment to an abrupt close.

On June 9, when the pumping was resumed, the water in the second well had risen to its normal level and did not again fall below $12\frac{1}{4}$ inches. A study of the record of the telltale will give some idea of the quantity of water at the location of this well, and from what area the well draws its supply, and how near to it similar wells might be located, and with what speed water travels through the sand at this point.

At a yield of 522.857 cubic feet per hour this well would, in one year of unintermitted pumping, yield sufficient water to cover 105 acres one foot deep.

During the test it will be observed that the water meter was showing so wide a variation in the efficiency of the pump that we do not place great reliance upon it. The meter, during the stop, was overhauled and again put in place before starting and much greater uniformity is noticeable afterwards.

Beginning with June 11 and ending September 1 the average efficiency of the pump as disclosed by the meter was 77.4 per cent. With this percentage of efficiency as a basis, and the record of June 22, 1896, when the theoretic quantity of water was 8,531 cubic feet the actual water pumped would be 6,603 cubic feet in actual pumping time 11 hours and 15 minutes or 9.78 cubic feet per minute equal to $73\frac{1}{4}$ gals.

At this rate pumping incessantly for a full year the amount of water would cover a fraction over 118 acres one foot deep. Pumping 10 hours per day 300 days per annum it would cover 40 acres one foot deep, which would probably be sufficient for all purposes.

The amount of gasoline consumed was 388.62 gallons. The total water pumped, 134,270 cubic feet, or sufficient to cover about 3.08 acres one foot deep; 338.62 gallons of gasoline at $13\frac{1}{2}$ cents per gallon would cost about $52.46, or about $14 per acre for 12 inches of water, to which should be added freight on gasoline from Kansas City to place of consumption.

The whole running time was 415 hours and 13 minutes. Discarding the minutes the amount of gasoline consumed per hour was .934 of a gallon.

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The total evaporation from July 1, 1896, to October 31, 1896, was 25⅞ inches. The rainfall for the period from June 4 to October 31, inclusive, was 8.76 inches.

On September 1, 1896, large quantities of sand were observed to be ejected from the well and the next day the pumped stopped, the plunger being impacted in sand.

In order to repair, it became necessary to draw the pipes. In doing this the casing was disturbed, and when the pipes were withdrawn the strainer broke in two pieces, one part remaining in the well and the well filled with sand to a depth of 103 feet from the surface.

An attempt was then made to restore the well by fishing out the casing and piece of the strainer and sinking the 8-inch pipe armed with a steel shoe and drilling inside of the pipe. In this manner the pipe was sunk to a depth of 131 feet, further progress being stopped by the pieces of galvanized casing interfering with the drilling. An 18-foot Cook strainer No. 10, 7½ inches in diameter, was let down and fastened in place, the pipe being drawn back, a working barrel inserted, and on November 17, 1896, the pump again started and in two hours the water was exhausted, showing that the upper stratum would not furnish a full supply.

This station is one of the most valuable established by the board and should not be abandoned by the state. In its present condition it is crippled by lack of water.

We would suggest in reference to it, that a well be made where this present one is, by sinking a 12-inch artesian well casing, inserted joints, to the bottom of the last water-bearing stratum if possible.

This casing would be large enough to enable the drillers to get out the galvanized iron casing that now obstructs the work. When the artesian casing has been sunk as deep as required there should be dropped inside of it heavy galvan-

RECORD OF STRATA passed through in sinking well at Station No. 5, west half of northwest quarter of section 3, township 11, range 32 west, sixth principal meridian, Logan county, Kansas.

Stratum and sample number.	Depth (in feet) from surface to—		Thickness (in feet) of stratum.	Distance, top of ground to first water.	Exact distance, top of ground to top of water when well finished.	Characteristics: Color, hardness, popular names, whether dry or water-bearing.
	Top of stratum.	Bottom of stratum.				
1	.....	3	3	93	93	Soil, dark loam, dry.
2	3	24	21	.....	.....	Yellow lime clay, dry.
3	24	33	9	.....	.....	Magnesia clay, moist.
4	33	44	11	.....	.....	Sand, gravel and rock, damp.
5	44	55	11	.....	.....	Red sand mixed with lime, damp.
6	55	65	10	.....	.....	Common sand and boulder rock, dry.
7	65	75	10	.....	.....	Brown sand, damp.
8	75	84	9	.....	.....	Red clay, damp.
9	84	90	6	.....	.....	Brown sand, damp.
10	90	5	5	.....	.....	Yellow damp sand and sand rock.
11	95	102	7	.....	.....	Water-bearing sand and gravel.
12	102	112	10	.....	.....	Clay, very sticky.
13	112	119	7	.....	.....	Water-bearing sand.
14	119	123	4	.....	.....	Clay.
15	123	126	3	.....	.....	Water-bearing sand.
16	126	128	2	.....	.....	Clay.
17	128	137	9	.....	.....	Water-bearing sand.
18	137	145	8	.....	.....	Clay.
19	145	148	3	.....	.....	Water-bearing sand.
20	148	155	7	.....	.....	Clay.
21	155	162	7	.....	.....	Water-bearing sand, rock bottom.

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ized iron tubing perforated with a cold chisel, from the inside, about 72 perforations to the lineal foot and of as large diameter as the artesian casing would admit.

This galvanized casing should extend from a short distance above the water to the bottom of the well and be perforated as above suggested from the top of the water to the bottom of the well, then enough of the artesian well casing should be drawn out and taken off to leave a lap upon the galvanized iron casing of at least 10 feet, and there secured in place.

Inside of this well casing the pump pipe eight inches in diameter should be suspended.

We are satisfied that the well thus made cannot be exhausted by any 8-inch plunger pump, and it will yield at all times a full supply of water.

In the spring of '96 this plant was leased to the State Agricultural College at Manhattan, and under its management experimental farming was done.

The success of their efforts was much impaired by great delays in obtaining necessary repairs and gasoline for the engine from the manufacturers.

STATION No. 6, WICHITA COUNTY.

This station was located upon the recommendation of Mr. Sutton upon land donated by Lydia H. Allphin and Charles R. Allphin, her husband, by deed dated April 2, 1895, and recorded in the office of the register of deeds of Wichita county, May 29, 1895, in book 8 of deeds, page 372, and its description is as follows:

"Commencing at the southeast corner of the northeast quarter of section 23, township 18 south of range 37 west, thence west 90 rods, thence north 80 rods, thence east 90 rods, thence south 80 rods to the place of beginning, except 5 acres in the southeast corner of said tract; said 5 acres being in the form of a square."

The contracts for the construction of this station were let May 14, 1895, as follows:

Well to G. B. Lawrence, Tribune, Kas.

Power to the Stover Manufacturing Co., Freeport, Ill.

Pump and tubing to the Woodmanse & Hewitt Manufacturing Co., Freeport, Ill.

Reservoir to Orra Wykoff, Leoti, Kas.

The total cost of this plant, including the second well, made necessary by the spoiling of the first one by the pump contractor's employees was $914.26.

Repairs $46.30; operating $15.

The depth of the well is 145 feet; depth to water, 75 feet.

The power is a 16-foot steel, back-geared, Ideal windmill on a 40-foot three post steel tower.

The reservoir is 80x125 feet; embankments 4 feet on outside and 5½ feet inside.

The pump is a 5½-inch Cook cylinder, and 6-inch pipe. The water supply is abundant.

The first well put down at this station was completed June 27, 1895, and was 163½ feet deep; to water, 74½ feet; the pump and power were put in very soon after.

The power was a 14-foot steel mill, called the Ideal, and the pump was a Woodmanse & Hewitt Manufacturing Co.'s butterfly valve.

About June 20, 1895, soon after completion, the pipe slipped from its fastenings and fell into the well.

The contractors at once endeavored to fish it out, and after much delay

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finally got out a part of the pipe, put it together again, replaced the pump and started the mill. It did not work satisfactorily and after further delays reaching down into the fall the contractors drew out the pipes and about October 8, 1895, put some gravel into the well, intending to fill it about 14 feet. When they stopped shoveling and took their soundings they had filled the well up to within 84 feet of the top, leaving but 10 feet of water. When the pump was put in and set to work the water was quickly exhausted. The contractors were notified immediately and after waiting a long time for them to remedy the evil and not discovering the proper disposition on their part to do it, the Board put down a new well.

This well was finished February 4, 1896; depth, 145 feet; depth to water 75 feet; the well was drilled; it is cased with No. 20 galvanized iron casing 8 inches in diameter for a depth of 135 feet from surface, and 13 feet of seven-inch casing of same material rests on the bottom of the well. This casing is perforated from top of water to bottom of well, about 72 perforations to the lineal foot, made from the inside with a cold chisel, and thereby water from every stratum is admitted to the well.

The 14-foot mill over the old well proved too small to run the pump except in a strong wind, and we arranged with the contractors to take it back and substituted a 16-foot mill for the new well. The old pump was put into the new well. The working of the pump was unsatisfactory and it was taken out and a Cook cylinder substituted for it. These changes were completed during June, 1896, since which time this plant has operated very satisfactorily.

The strata records of the two wells are here given:

FIRST WELL.

RECORD OF STRATA passed through in sinking well at Station No. 6, southeast quarter of northeast quarter of section 23, township 18, range 37 west, sixth principal meridian, Wichita county, Kansas.

Stratum and sample number.	Depth (in feet) from surface to—		Thickness (in feet) of stratum.	Distance, top of ground to first water.	Exact distance, top of ground to top of water when well finished.	Characteristics: Color, hardness, popular names, whether dry or water-beoring.
	Top of stratum.	Bottom of stratum.				
1	.....	7	7	74½	69	Dark loam.
2	7	11⅞	11	.....	.....	Whitish marl.
3	11⅞	22	11⅛	.....	.....	Soft gypsum, gray color.
4	22	27	5	.....	.....	Hard clay, yellow.
5	27	32½	5½	.....	.....	Coarse, hard sand.
6	32½	55½	23	.....	.....	Hard gypsum, white.
7	55½	74½	19	.....	.....	Sandy clay, soft.
8	74½	78	3½	.....	.....	Fine water sand, first water.
9	78	90	12	....	.....	Hard clay; some indications of gypsum seams where water seemed to increase.
10	90	104	14	.....	.....	Magnesia; light yellow sample more or less mixed with sand from No. 8.
11	104	107	3	.....	.....	Fine water sand; gave most trouble in drilling; red.
12	107	116	9	.....	.....	Hard gray sand, with seams of quicksand; sample mixed with No. 11, which run in all the time.
13	116	129	13	.....	.....	Sandy clay, gray color.
14	129	134	5	.....	.....	Water sand and small gravel would indicate lots of water.
15	134	161½	27½	.....	.....	Yellow chalk or shale.
16	161½	163½	2	.....	.....	Black shale.

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SECOND WELL.

RECORD OF STRATA passed through in sinking well at station No. 6, section 23, township 18, range 37 west, sixth principal meridian, Wichita county, Kansas.

Stratum and sample number.	Depth (in feet) from surface to—		Thickness (in feet) of stratum.	Distance, top of ground to first water.	Exact distance, top of ground to top of water when well finished.	Characteristics: Color, hardness, popular names, whether dry or water-bearing.
	Top of stratum.	Bottom of stratum.				
1	.....	1	1	75	75	Surface soil.
2	1	12	11	.....	.....	Marl.
3	12	22	10	.....	.....	Gypsum.
4	22	32	10	.....	.....	Clay.
5	32	55	23	.....	.....	White stone.
6	55	74	19	.....	.....	Sand and clay.
7	74	79	5	.....	.....	Sand and clay, first water.
8	79	91	12	.....	.....	Coarse sand, lots of water.
9	91	109	18	.....	.....	Fine clay.
10	109	138	29	.....	.....	Hard sand and cement.
11	138	143	5	.....	.....	Sand, a good water sand.
12	143	145	2	.....	.....	Went two feet in yellow chalk or clay.

The fact that the pump in the first well located about 80 feet from the surface quickly exhausted the water, shows that the first water is in small supply and that the lower stratum is not strongly artesian in its nature or water would have come up from below to supply the pump.

Comparing the strata records of the two wells, about 100 feet apart, we see the strata are not the same.

In the first well 78 to 90 — 12 feet of hard clay.

In the second well, 79 to 91 — 12 feet of coarse sand, lots of water.

First well 129 to 134 "water sand and small gravel would indicate lots of water."

Second well, 138 to 143, "sand, a good water sand."

This is one of the best stations — plenty of water, power well proportioned to the work required, and in a locality offering every advantage for irrigation by pumping. This station should be utilized by the state for further experiment.

STATION No. 7. GREELEY COUNTY.

This station was recommended by Mr. Sutton upon the northwest quarter of the southwest quarter of section 22, township 18, range 40, Greeley county, the land having been donated for the purpose by Mr. Henry Weaver, of Tribune, Kas.

A well was sunk 70 feet deep, reaching the black shale without finding water. After personal examination of the well and surroundings it was decided to abandon the station and return the deed to the donor, which was done.

The amount expended by the Board on this well was $95.21.

It would be error to conclude that Greeley county has no underflow because this well failed to reach water. In places there are prominent underground ridges in the shale floor on which the tertiary rests which rise above the water level. Consequently shale is encountered before the water is reached. In such cases the well should be abandoned unless it is the intention to penetrate the shale to discover what may be beneath it.

The strata record of the well is given on the opposite page.

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RECORD OF STRATA passed through in sinking well at station No. 7, section 22, township 18, range 40 west, sixth principal meridian, Greeley county, Kansas.

Stratum and sample number.	Depth (in feet) from surface to—		Thickness (in feet) of stratum.	Distance, top of ground to first water.	Exact distance, top of ground to top of water when well finished.	Characteristics: Color, hardness, popular names, whether dry or water-bearing.
	Top of stratum.	Bottom of stratum.				
1	.....	2½	2½	.....	.....	Black loam.
2	2½	15	12½	.....	.....	Marl.
3	15	35	20	.....	.....	Sand and gravel.
4	35	37	2	.....	.....	Cement and gravel, hard.
5	37	44	7	.....	.....	Clay.
6	44	68	24	.....	.....	Yellow chalk or shale.
7	68	70	2	.....	.....	Black shale.

A small trace of water at 35 feet, none after—a dry hole.

STATION No. 8. LANE COUNTY.

This station was located upon the recommendation of Mr. Sutton upon the southeast ¼ of the northeast ¼ of section 13, township 18, range 29, Lane county.

The land was donated by the British and American Mortgage company (limited) of London, England, by deed dated April 7, 1895, and recorded in the office of the register of deeds of Lane county, in book 9, p. 170, on the first day of June, 1895.

The contracts for the construction of the station were let as follows:

Well and reservoir, W. A. Tyner, Dighton, Kas.

Pump and power, Woodmanse & Hewitt Manufacturing Co., Freeport, Ill.

The cost of this plant was $498.48.

Repairs, $35.85; operating, $4.

The depth of the well is 89 feet. It is an open well 8 inches in diameter cased with No. 20 galvanized iron casing perforated below water. Depth to water is 52 feet.

It reaches the black shale and consequently penetrates all the water bearing sands of the tertiary deposits at this point.

The pump is a 6-inch cylinder with butterfly valves and made by the contractor. It is affixed to the end of 60 feet of 6-inch pipe and below is 16 feet of 4-inch pipe.

The windmill is a 14-foot Woodmanse Mogul, steel, back-geared wheel.

The storm of April 28, 1896, blew over the mill and tower and afterwards upon notice to the contractors, they replaced the same with a new and improved Mogul mill and tower at their own expense. This was completed in the early part of June, 1896, since which time the station has worked very satisfactorily.

Mr. J. G. Frank, of Great Bend, who erected the last mill and tower, under date of December 31, writes as follows:

"I never before or since in 14 years' experience saw a better windmill pumping plant. After pumping 14 or 15 hours the water supply proved good and pumped as clear water as at first. I say it fearless of contradiction, that this is the best plant, well and all the machinery together, of all the state plants that I visited. This plant is a credit to the State Board and the people."

There is fine sand in this as in many other localities, and in a new well it cuts out leathers very fast. Time and pumping seem to be the only remedy.

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The reservoir gave some trouble by leaking. Ordinary puddling did not have the usual effect of making the walls and bottom water tight. The experiment of stirring up the water with a harrow till it was of the consistency of cream was tried with good effect. In cases where the water seeps out without having any distinct channel in which to flow, this is very effective treatment. Water is made muddy by carrying in suspension minute particles of soil. As this muddy water goes into the banks and bottom of the reservoir it deposits in its course the fine particles it carries, and more following makes further deposits, until the interstices in the soil are completely filled and cemented, the result is in time a water-tight reservoir.

The strata record of this well is here given:

RECORD OF STRATA passed through in sinking well at Station No. 8, section 13, township 18, range 29 west, sixth principal meridian, Lane county, Kansas.

Stratum and sample number.	Depth (in feet) from surface to—		Thickness (in feet) of stratum.	Distance, top of ground to first water.	Exact distance, top of ground to top of water when well finished.	Characteristics: Color, hardness, popular names, whether dry or water-bearing.
	Top of stratum.	Bottom of stratum.				
1.....	.....	2	2	52	52	Black soil.
2.....	2	16	14	.....	.....	Yellow clay.
3.....	16	36	20	.....	.....	Magnesia stone.
4.....	36	56	20	.....	.....	Sandstone and sand.
5.....	56	74	18	.....	.....	Sandstone and glint stone.
6.....	74	79	5	.....	.....	Sand.
7.....	79	89	10	.....	.....	Soapstone.

STATION No. 9. HASKELL COUNTY.

This station was located on the recommendation of Mr. Frost upon the N.E. ¼ of the S.W. ¼ of Sec. 25 in T. 28, R. 33, which land was donated to the state of Kansas by Addison W. Stubbs and Edith P.; his wife, of Garden City, Kas., by deed dated April 23, 1895, and recorded in the office of register of deeds of Haskell county, November 11, 1895, in book No. 10, page 136.

After due notice the contracts for this station were let as follows:

Pump and power The United States Water and Steam Supply Company, Kansas City, Mo.

Well, to John C. Buster, H. Glazier, Santa Fe, and G. E. Studebaker, of McPherson.

Reservoir, John C. Buster, of Santa Fe.

The cost of the construction of this plant was $1,895.80; repairs, $220.13; operation, $5.

The well is 291 feet deep. Depth to water, 202 feet.

The power is a 25-foot sectional wooden wheel, known as the Halladay Standard, and is erected on a 40-foot wooden tower.

This plant, upon completion, worked well for a short time and supplied abundance of water, but after a time, through some defect of the strainer, the pump began to take in sand and finally filled the cylinder and stopped. Efforts were made to draw the pipe, but all failed. Finally the pipe was cut off at the water's edge and an 8 inch 8 foot sand point, with brass jacket, was sunk 28 feet alongside of the pipe, and a new pipe and pump were suspended inside of the brass jacket. The well is again yielding an abundant supply of water from the first water strata, consisting of 9 feet of coarse gravel.

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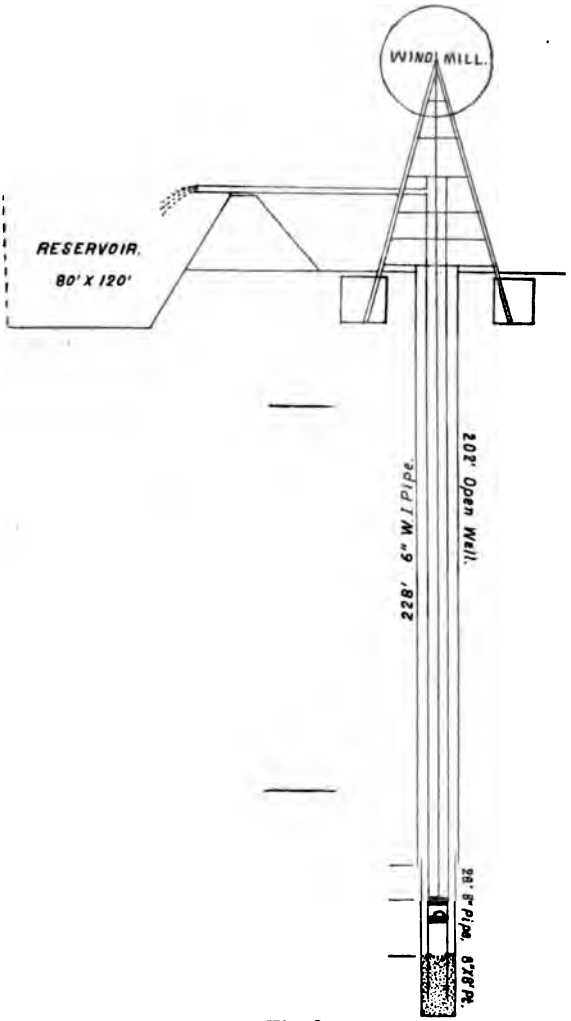

Fig. 3.

Station No. 9, Haskell county. (Santa Fe.)

DETAILS.

25-foot Halladay wooden wheel.
40-foot 8x8-inch wooden tower.
3x3x5-foot stone foundation.
231 feet of 6-inch wrought-iron pipe.
223 feet of 2-inch octagon ash pumping rods.
6x42-inch Cook's cylinder.
202 feet of dug well.
23½ feet of 8-inch wrought-iron pipe.
8x30-inch brass jacket point.

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STATION No. 10. TREGO COUNTY.

This station was located on the recommendation of Mr. Sutton on the southeast quarter of the southeast quarter of section 2, township 12, range 23, Trego county.

The land for the same was donated by ———.

A well was sunk 110 feet to black shale and so small a quantity of water obtained that the station was abandoned and the deed returned to the donors unrecorded.

The amount expended on this station was $120.

This well is on the eastern edge of the underflow territory. This eastern boundary appears to be a jagged line, (see map), and while some good wells may be found to the eastward of this location, the chances for water are better westward. The shale floor projects upwards in places in the longitude of this location, and the water cannot be found in every place.

The strata record of the well is here given:

RECORD OF STRATA passed through in sinking well at Station No. 10, southwest quarter of southeast quarter of section 2, township 12, range 23 west, sixth principal meridian, Trego county, Kansas.

Stratum and sample number.	Depth (in feet) from surface to—		Thickness (in feet) of stratum.	Distance, top of ground to first water.	Exact distance, top of ground to top of water when well finished.	Characteristics: Color, hardness, popular names, whether dry or water-bearing.
	Top of stratum.	Bottom of stratum.				
1	.....	3	3	.....	.....	Dark soil, alluvial.
2	3	20	17	.....	.....	Brown yellow soft ochre, sand, clay.
3	20	60	40	.....	.....	Conglomerate, hard and soft in layers, from brown sand clay, gravel rock, white in 2- and 4-foot layers.
4	60	81	21	.....	.....	Sand and clay, gravel, usually water-bearing.
5	81	90	9	.....	.....	White rock hard on top, softer at 87 feet, changing to sandstone.
6	90	96	6	.....	.....	Sand clear white, water-bearing.
7	96	108	12	.....	.....	Clay, chalk, magnesia limestone soft.
8	108	110	2	.....	.....	Shale.

STATION No. 11. RAWLINS COUNTY.

This station was located, upon the recommendation of Mr. Tomblin, upon the southeast quarter of the northeast quarter of section 19, township 3, range 36, upon lands donated by Mary E. Means and J. W. Means, husband and wife, by deed dated November 15, 1895, recorded on the —— day of ———, 189–, in the office of the register of deeds of Rawlins county, in book No. —, p. —.

After due notice for bids the contract for the erection, complete, of this plant was let to Wm. Thompson, of Goodland, Kas.

The cost of this plant was $914.50; repairs, $87.78.

The well is tubular; total depth, 213 feet; diameter, 5 inches; depth to water, 188 feet. The pump has a Cook working barrel 4½ inches in diameter, 42 feet in length; a 16-foot Cook Strainer No. 10, which is located in the lowest water-bearing stratum, and furnishes abundance of water.

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The windmill is a 16-foot steel b. g. "Ideal;" the water lift to the outlet pipe is 193 feet, and the stroke 12 inches.

The mill is not equal to the task of running it as constantly as it should and a 4-inch cylinder would probably supply more water, as the mill so loaded would make more revolutions.

The reservoir did not hold water when first completed, and later on the banks on three sides were rebuilt and repuddled, after which it has given excellent results.

The underflow at this location yields an abundance of water and the soil well puddled makes a very good reservoir.

The strata record of the well is here given:

RECORD OF STRATA passed through in sinking well at Station No. 11, southeast quarter of northeast quarter of section 19, township 3, range 38 west, sixth principal meridian, Rawlins county, Kansas.

Stratum and sample number.	Depth (in feet) from surface to—		Thickness (in feet) of stratum.	Distance top of ground to first water.	Exact distance, top of ground to top of water when well finished.	Characteristics: Color, hardness, popular names, whether dry or water-bearing.
	Top of stratum.	Bottom of stratum.				
1	.....	2	2	.....	.....	Black soil.
2	2	32	30	.....	.....	Light soil.
3	32	98	66	.....	.....	Red clay.
4	98	116	18	.....	.....	Magnesia.
5	116	122	6	.....	.....	Hard rock.
6	122	124	2	.....	.....	Sand rock.
7	124	128	4	.....	.....	Flint rock.
8	128	138	10	.....	.....	Sand and rock.
9	138	164	26	.....	.....	Dry sand.
10	164	170	6	.....	.....	Gravel and sand.
11	176	190	20	.....	.....	Sand and clay; first water 188 feet in sand and clay.
12	190	213	23	.....	.....	Water sand, hard soapstone in bottom of stratum.

STATION No. 12. ROOKS COUNTY.

This plant was located on the recommendation of Mr. Tomblin upon the — ¼ of — ¼ of Sec. —, T. —, R. —, Rooks county, the land being donated by deed executed and delivered by ——— and his wife ———, to the state of Kansas.

The contracts were let to Crane & Co., Kansas City, Mo., and cost $641.90; repairs $100.40.

The well is 59 feet deep; to water, 34 feet, and reaches black shale.

The well was dug 34 feet to water, then a galvanized iron casing stoutly ribbed and hooped, 4 feet and 3 inches in diameter was sunk 12 feet; below this another galvanized casing similarly made, 2 feet and 6 inches in diameter, was sunk 9 feet and inside of this is a 6-inch hole bored to shale, finding but little water below 55 feet. Both casings below water were perforated.

Above the galvanized-iron casing and to surface of ground the well was walled with stone.

The pump is a 5x30 in. Frizell tubular cylinder; the pipe was 5 inches oil-well casing and pump rods are ¾ inch galvanized iron pipe; the power is a 14-foot Crane Irrigator on a 40-foot tower.

The supply of water is not great and not in excess of the capacity of the pump.

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RECORD OF STRATA passed through in sinking well at Station No. 12, Rooks county, Kansas.

Stratum and sample number.	Depth (in feet) from surface to—		Thickness (in feet) of stratum.	Distance, top of ground to first water.	Exact distance, top of ground to top of water when well finished.	Characteristics: Color, hardness, popular names, whether dry or water-bearing.
	Top of stratum.	Bottom of stratum.				
1	.....	3	3	.....	.....	Soil, very rich.
2	3	8	5	.....	.....	Soil gradually changing in color and very hard and dry.
3	8	13	5	.....	.....	Very hard and dry.
4	13	15	2	.....	.....	Red in color and sandy.
5	15	27	12	.....	.....	Clear sand and dry.
6	27	29	2	.....	.....	———
7	29	37	8	.....	.....	———
8, 9, 10	37	55	18	.....	.....	The last three feet was water-bearing. Nos. 8, 9 and 10 were found to be very soft sand rock gradually changing and becoming softer as we went deeper.

With No. 6 auger we bored below bottom of well to shale, making a total depth of 59 feet, 8 inches. A vein of water-bearing sand and gravel about six inches thick was found at about 56 or 57 feet.

STATION No. 13. FORD COUNTY.

This station was located on the recommendation of Mr. Frost upon 40 acres of land in the southwest quarter of section 14, township 26, range 25, in Ford county, donated to the state by E. H. Vaughan, and Emma T., his wife, by deed dated September 14, 1895, and recorded in the office of register of deeds, Ford county, on the 22d day of October, 1895, in book 24, page 277.

The contracts for this station were let to the Frizell Hardware Company, Larned, Kas.

The station cost $927.37; repairs, $161.14.

The accompanying cut shows the well, pump, mill, and location of reservoir, which is 80x120 feet, with embankments 4 feet high outside and 7 feet 1 inside.

Sand in this well gave much trouble, filling the cylinder and requiring the pulling of the pipes three times, and each time cleaning out and deepening the well. The plant is now in good running order, and the well 192 feet deep.

RECORD OF STRATA passed through in sinking well at Station No. 13, southeast quarter of southeast quarter of section 14, township 26, range 25 west, Ford county, Kansas.

Stratum and sample number.	Depth (in feet) from surface to—		Thickness (in feet) of stratum.	Distance, top of ground to first water.	Exact distance, top of ground to top of water when well finished.	Characteristics: Color, hardness, popular names, whether dry or water-bearing.
	Top of stratum.	Bottom of stratum.				
1	2	70	68	.....	.....	Yellow, hard.
2	70	97	26	.....	.....	Gypsum, hard, white.
3	97	101	4	.....	.....	Gray formation.
4	101	103	2	.....	.....	Sand rock.
5	103	117	14	.....	.....	Sand and magnesia.
6	117	130	13	.....	.....	Gravel.

This measurement is 3 feet from top.

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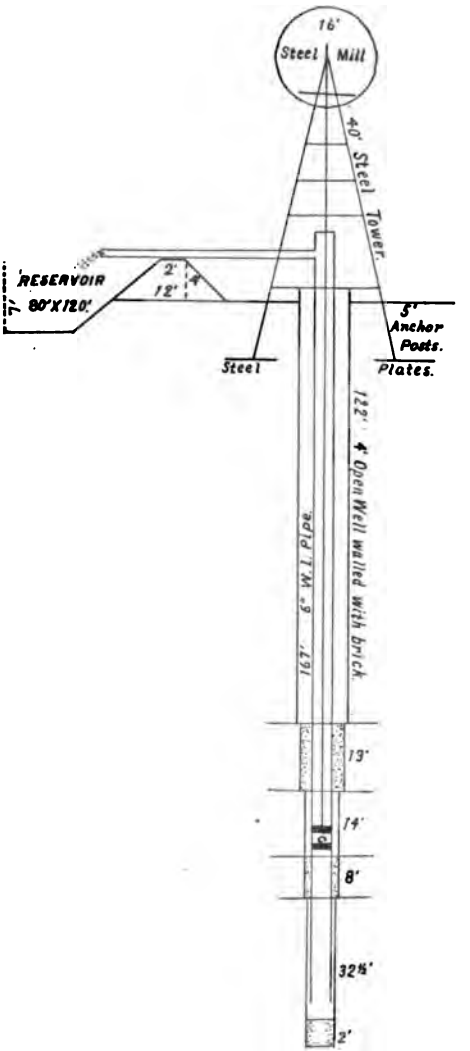

Fig. 4.

Station No. 13, Ford county. (Dodge City.)

DETAILS.

16-foot "Ideal" back-gear steel mill.
40-foot 3-post galvanized-steel tower.
5-foot galvanized-steel anchor-posts.
20-inch cast-iron anchor-plates.
5¾x30-inch Frizell tubular cylinder.
167 feet of 6-inch wrought-iron pipe.

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STATION No. 14. SEWARD COUNTY.

Located on recommendation of Mr. Frost on northeast quarter of northeast quarter of section 31, township 34, range 33, Seward county, donated by E. O. DeVoss and Lucy L., his wife, and deed recorded in the office of register of deeds of Seward county, on the 27th day of November, 1896, in deed book E, page 42.

The contract for this work was let:

Well, to E. Dudley, Moscow, Kas.

Reservoir, W. H. McCammon, Ulysses, Kas.

Pump, power and materials, Fairbanks, Morse & Co., Kansas City, Mo.

The accounts for construction and repairs upon this station have not as yet been audited by the board.

Total depth of well originally was 172 feet. The well is bored, and is cased 146 feet with galvanized iron casing 8 inches in diameter. The station consists of well, pump and windmill.

After this well had been finished and the mill and tower erected, the cylinder filled with sand, and the pump and pipes had to be drawn out — in this operation the strainer was broken and a part left in the well. A new strainer was supplied, the well cleaned out, since which time it has worked very well. The supply of water is sufficient for the pump. A drawing of the well and the strata record are here given.

RECORD OF STRATA passed through in sinking well at Station No. 14, northeast quarter of northeast quarter of section 31, township 34, range 33 west, Seward county, Kansas.

Stratum and sample number.	Depth (in feet) from surface to—		Thickness (in feet) of stratum.	Distance, top of ground to first water.	Exact distance, top of ground to top of water when well finished.	Characteristics: Color, hardness, popular names, whether dry or water-bearing.
	Top of stratum.	Bottom of stratum.				
1	.....	2	2	109	109	Soil and subsoil.
2	2	9	7	.....	.....	Sand.
3	9	17	8	.....	.....	Sandy clay.
4	17	20	3	.....	.....	Gypsum clay.
5	20	32	12	.....	.....	Clay, brown.
6	32	35	3	.....	.....	Hard clay.
7	35	37	2	.....	.....	Sandstone.
8	37	43	6	.....	.....	Sand and soft sandstone.
9	43	57	14	.....	.....	Hard gray clay.
10	57	60	3	.....	.....	Hard rock.
11	60	80	20	.....	.....	Sandy clay and sandstone.
12	80	85	5	.....	.....	Hard sandstone.
13	85	98	13	.....	.....	Hard sandy clay.
14	98	104	6	.....	.....	Hard sandstone.
15	104	109	5	109	109	Very hard stone, water.
16	109	111	2	.....	.....	Artesian clay, gray, and limestone.
17	111	115	4	.....	.....	Four feet very hard sandstone.
18	.....	.....	109	109	.....	
19	111	118	7	.....	.....	Sand, gravel, second water strata.
20	118	122	4	.....	.....	Joint clay.
21	122	130	8	.....	.....	"
22	130	135	5	.....	.....	Quicksand, third water strata.
23	135	137	2	.....	.....	Gumbo, two ft. of sand, fourth water strata.
24	137	172	35	.....	.....	Artesian clay.

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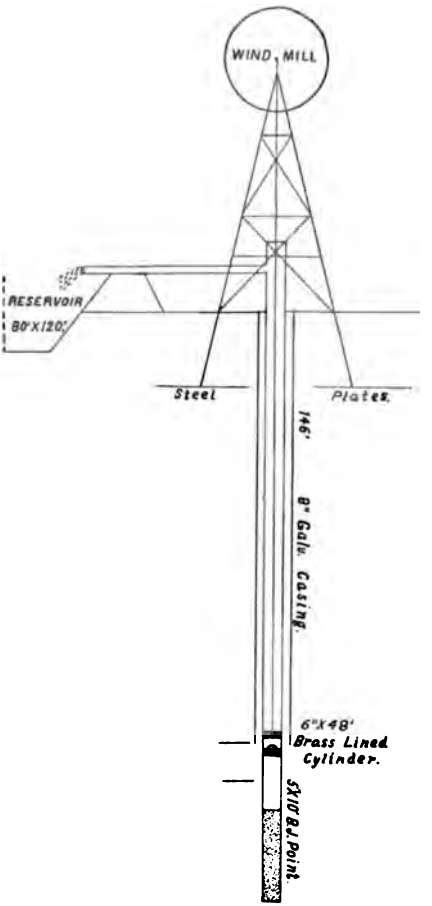

Fig. 5.

Station No. 14, Seward county. (Liberal.)

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STATION No. 15. SHERIDAN COUNTY.

Failure to secure a suitable location in accordance with the law prevented the erection of this station.

STATION No. 16. HODGEMAN COUNTY.

This station was located on recommendation of Mr. Frost on southwest quarter of the southeast quarter of section 35, township 22, range 24, Hodgeman county, donated by Frank C. Owens and wife by deed dated April 1, 1896, and recorded in the office of the register of deeds of Hodgeman county, November 28, 1896, in book 9, p. 246.

The contracts for the station were let to the Frizell Hardware Company on May 5, 1896. The cost of construction $1,272.08, operation $15.50.

The station consists of well, pump, windmill and tower, and reservoir 80x120 feet, 7 feet deep.

This is a drilled well 277 feet deep and cased with galvanized iron casing 9 inches in diameter, inside of which the pump is suspended.

This station is not on the tertiary formation which holds the western underflow proper, but reaches through the shale which is the floor of the tertiary and penetrates the Dakota sandrock. The first water is struck at 186 feet, but the water stands in the well 128 feet from the surface, showing to the extent of 60 feet it is artesian.

A drawing of the mill and well and the strata records are appended.

RECORD OF STRATA passed through in sinking well at Station No. 16, section 35, township 22, range 24 west, sixth principal meridian, Hodgeman county, Kansas.

Stratum and sample number.	Depth (in feet) from surface to—		Thickness (in feet) of stratum.	Distance, top of ground to first water.	Exact distance, top of ground to top of water when well finished.	Characteristics: Color, hardness, popular names, whether dry or water-bearing.
	Top of stratum.	Bottom of stratum.				
1	.....	26	26	.....	.....	Soil and magnesia, dry.
2	26	44	18	.....	.....	Limestone, dry.
3	44	55	11	.....	.....	Black shale, dry.
4	55	99	44	.....	.....	Gray shale, dry.
5	99	104	5	.....	.....	Soapstone, dry.
6	104	126	22	.....	128	Sand rock, dry.
7	126	129	3	.....	.....	Gray shale, dry.
8	129	186	57	186	.....	Black shale, dry.
9	186	210	24	.....	.....	Sand rock, water-bearing.
10	210	218	8	.....	.....	White clay.
11	218	223	5	.....	.....	Red clay.
12	223	243	20	.....	.....	White clay.
13	243	250	7	.....	.....	Sand rock, water-bearing.
14	250	264	14	.....	.....	White clay.
15	264	275	11	.....	.....	Sand rock, strong flow water.
16	275	277	2	.....	.....	Blue clay, depth unknown.

STATION No. 17. TREGO COUNTY.

This station was located, on the recommendation of Mr. Sutton, upon the northwest quarter of the northwest quarter section 15, township L, range 23; donated by Hon. E. N. Morrill and Carrie J., his wife.

A well was sunk on this land 116 feet deep, reaching the black shale without finding water.

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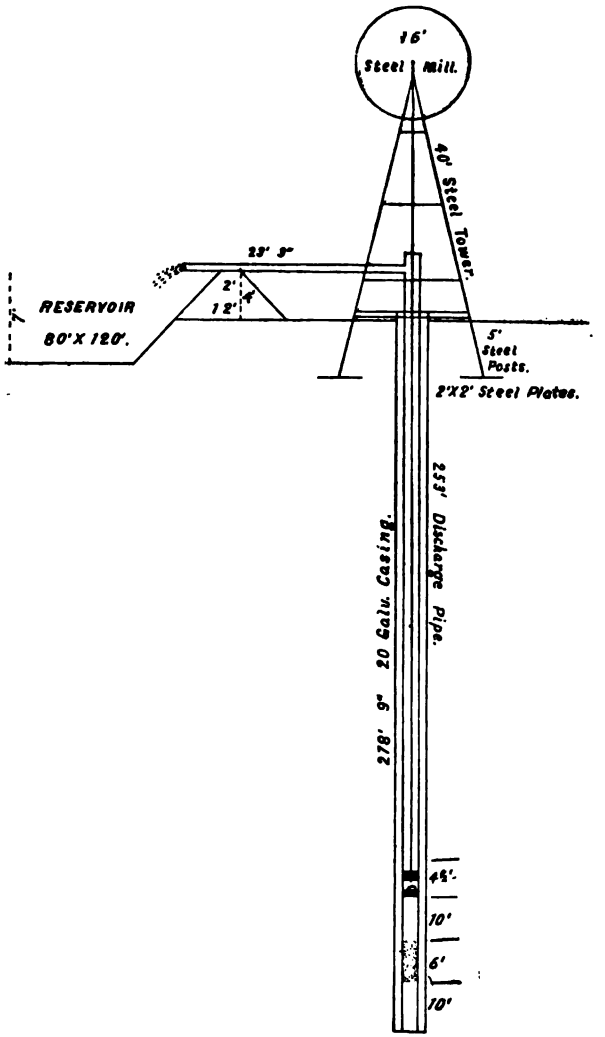

Fig. 6.

Station No. 16, Hodgeman county. (Jetmore.)

DETAILS.

16-foot Fairbanks back-gear steel mill.
40-foot 4-post galvanized-steel tower.
5-foot galvanized-steel anchor-posts.
2x2-foot galvanized-steel anchor-plates.
278 feet of No. 20 9-inch galvanized casing.
283 feet of 5-inch wrought-iron pipe.
260 feet of 2½-inch round ash rods.
5x54-inch brass-lined tubular cylinder.
5x72-inch brass jacket point.

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Total amount expended, $119.

Trego county lies on the eastern edge of the western underflow, and in places the shale penetrates the tertiary deposits. This well was upon one of these shale elevations and consequently proved a dry hole. It by no means follows that there is no underflow in Trego county.

The deed for this land was returned to Governor Morrill unrecorded, and the station abandoned.

The strata record is here given:

RECORD OF STRATA passed through in sinking well at Station No. 17, northwest quarter of northwest quarter of section 15, township 12 south, range 23 west, sixth principal meridian, Trego county, Kansas.

Stratum and sample number.	Depth (in feet) from surface to—		Thickness (in feet) of stratum.	Distance top of ground to first water.	Exact distance, top of ground to top of water when well finished.	Characteristics: Color, hardness, popular names, whether dry or water-bearing.
	Top of stratum.	Bottom of stratum.				
1			1½			Black soil; soft, dry.
2			4½			Clay soil; soft, dry.
3			3			Light-yellow clay; hard.
4			2			Red dirt; hard.
5			2½			Sand; soft.
6			12			Magnesia; hard.
7			9			Red clay; hard.
8			2			Magnesia and clay; soft.
9			9			Yellow clay.
10			7			Light sand.
11			12			Clay; dark, hard.
12			8			Magnesia rock; hard.
13			10			Sandstone; very hard.
14			3			Light sand.
15			10			Yellow sand.
16			2½			Hard rock under yellow sand.
17			4			Sand and clay; soft.
18			10			Yellow rock; soft.
19			6			Dark shale.
20			2			Shale.

STATION No. 18. GREELEY COUNTY.

This station was located on the recommendation of Mr. Sutton upon the N. W. ¼ of S.E. ¼ of Sec. 17, T. 18, R. 40; donated by J. U. Brown and wife, of Tribune, Kas., in March, 1896.

RECORD OF STRATA passed through in sinking well at Station No. 18, northwest quarter of south east quarter of section 17, township 18, range 40 west, sixth principal meridian, Greeley county, Kansas.

Stratum and sample number.	Depth (in feet) from surface to—		Thickness (in feet) of stratum.	Distance, top of ground to first water.	Exact distance, top of ground to top of water when well finished.	Characteristics: Color, hardness, popular names, whether dry or water-bearing.
	Top of stratum.	Bottom of stratum.				
1		1	1			Top soil.
2	1	15	14			Marl.
3	15	24	9			Gypsum, soft.
4	24	79	55			Compact sand, soft.
5	79	88	9			Loose sand, dry.
6	88	92	4			Gypsum.
7	92	95	3			Loose sand, dry.
8	95	100	5			Tough yellow clay.
9	100	100½	½			Water sand, about 6 in.
10	100½	113	12½			Yellow shale.
11				100	96	Black shale.

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A well was sunk on this land a total depth of 113 feet, reaching black shale. This was also a case where the shale floor on which the tertiary rests projected into the tertiary.

Total expended at this station, $113.

The station was abandoned and the deed returned to the donor, unrecorded.

STATION No. 19. WALLACE COUNTY.

This station was located on recommendation of Mr. Sutton and is situated on the northeast ¼ of the southeast ¼ of section 26, township 13, range 40, Wallace county, donated by Olof Nelson and Christine, his wife, to the state of Kansas, dated May 1, 1896, and recorded in the office of the register of deeds of Wallace county, in book A, page 504 of deeds.

After due notice the contracts for the work were let as follows:

Well, pump and power, W. P. A. Carter, Weskan, Kansas.

Reservoir to O. C. Nelson, Sharon Springs, Kansas.

The total cost of this plant, $588.34; operation, $10; repairs, $15.

The plant consists of a dug well 33 feet, and a 12-inch hole, the further depth of 11 feet cased with galvanized iron tubing 12 inches in diameter, perforated to admit water. The pit is 6 feet deep, and the next 27 feet is cased with vitrified tiling 15 inches in diameter.

Depth to water, 32½ feet.

A 12-foot Fairbanks, Morse & Co. steel mill, 40-foot tower and 6-inch pump.

Reservoir 80x80 feet.

This well reaches the shale.

The water supply is not sufficient for the pump.

RECORD OF STRATA passed through in sinking well at Station No. 19, northeast quarter of northeast quarter of section 26, township 13, range 40 west, sixth principal meridian, Wallace county, Kansas.

Stratum and sample number.	Depth (in feet) from surface to—		Thickness (in feet) of stratum.	Distance, top of ground to first water.	Exact distance, top of ground to top of water when well finished.	Characteristics: Color, hardness, popular names, whether dry or water-bearing.
	Top of stratum.	Bottom of stratum.				
1	.....	4	4	32½	32½	Black loam.
2	4	7	3	.....	.....	Red sandy loam.
3	7	12	5	.....	.....	" "
4	12	17	5	.....	.....	Sand.
5	17	21	4	.....	.....	Sandy loam.
6	21	24	3	.....	.....	Sandy loam mixed with alkali moist from underneath.
7	24	27	3	.....	.....	Same as above (No. 6.)
8	27	32½	5½	.....	.....	" " "
9	32½	35	2½	.....	.....	Water-bearing sand and clay.
10	35	37½	2½	.....	.....	Same as above (No. 9.)
11	37½	40	2½	.....	.....	" " "
12	40	42	2	.....	.....	" " "
13	42	44	2	.....	.....	Water-bearing sand and gravel.
14	44	45	2	.....	.....	Clay mixed with sand, red and hard. Next, shale.

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GEOLOGY.

Any accurate knowledge of the underflow waters involved an extended investigation into the geological structure of our territory. The Board was fortunate in having Prof. Erasmus Haworth, of the University, connected with it, as it thereby secured his services gratuitously to take charge of and make a study of the geological conditions governing underground water.

By combining the geological appropriation of the regents of the University with funds of the Board, and placing all under the immediate management and supervision of Professor Haworth, a more extended study and investigation into the geology of western Kansas was made than had heretofore been undertaken. The results of 1895 were so satisfactory that the scope of the work was enlarged in 1896 and the number of assistants increased and small monthly salaries were paid to a few of them.

Professor Haworth gave his time, energy and skill to the work without compensation from the Board.

Professor Haworth has contributed to our report the following article embodying the results of this investigation.

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The Geology of Underground Water in Western Kansas.

BY ERASMUS HAWORTH.

INTRODUCTION.
General Conditions Regulating Underground Water.
(*a*) In Humid Countries.
(*b*) In Arid Countries.
Outlines of Kansas Geology.
(*a*) The Carboniferous and Permian.
(*b*) The Red-Beds.
(*c*) The Dakota.
(*d*) The Benton.
(*e*) The Niobrara.
(*f*) The Fort Pierre.
(*g*) The Tertiary and Pleistocene.
Character of the Floor.
Classes of Underground Water.
WATER IN THE DAKOTA SANDSTONE.
Character of the Dakota Water.
Localities where Dakota Water may be Sought.
TERTIARY UNDERGROUND WATER.
How the Water Occurs.
Depth at Which Water is Found.
Eastward Movement of the Water.
Tertiary Springs.
Areal Extent of Tertiary Water.
Tertiary Artesian Wells.
Artesian Wells of Meade County.
Geography.
Geology.
Water Not Artesian.
The Artesian Wells.
Well of F. W. Foster.
Source of the Artesian Water.
Springs in the Artesian Valley.
Quantity of Available Water in the Artesian Valley.
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Local Rainfall.
Mountainous Water.
Amount of the Underground Water.
Discussion of Special Areas.
General Upland Areas.
The Arkansas River Valley.
The McPherson Area.
Special Areas Described by Doctor Adams.
Jetmore to Larned.
Little Walnut Creek Area.
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Big Timber Creek Area.
Dighton and Ransom to State Line.
Oakley Area.

INTRODUCTION.

It was known in a general way before these investigations were begun that the principal localities where any considerable underground water was available were covered with Tertiary deposits, or that they were areas over which the Dakota sandstone could be reached by the drill. Preliminary maps had been published by different authors, showing the approximate outlines of the Tertiary and Dakota areas. Little had been published, however, showing the true relation between the Tertiary sands and the underground water, while much less had been published giving a clear conception of the relation of the underground Cretaceous floor to the underground water. If possible, still less had been published in a form available to the average citizen showing the relation of the Dakota sandstone formations and the artesian water of the state. Since the work was begun a most excellent pamphlet has been issued by Mr. Gilbert,* of the United States Geological Survey, giving in a convenient manner many facts regarding underground water along the Arkansas river valley in Colorado. As this territory is so close to parts of Kansas territory under consideration, Mr. Gilbert's paper becomes of special interest to citizens of Kansas.

*The Underground Water of the Arkansas Valley, by Grove Karl Gilbert. Extract from the Seventeenth Annual Report of the Director of the United States Geological Survey, 1895-'96.

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Our investigations were confined principally to four subjects: First, a more accurate mapping of the Tertiary and Dakota areas of the state; second, a more detailed study of the character and position of the floor underlying the Tertiary areas and its relation to the overlying water-bearing sands; third, the underground water obtained within the Tertiary deposits; fourth, the water contained within the Dakota sandstones. In conducting these observations it was deemed advisable to effect a cooperation between the Board of Irrigation and the department of Physical Geology of the State University. The University is authorized by legislative enactment to conduct a Geological Survey of the state, and the Board of Regents has declared the department of the University Geological Survey organized and in operation. The University was therefore wishing to obtain information regarding the general geologic conditions of western Kansas. It became apparent that by having a proper cooperation work could be done for each organization at but little less expense than would be necessary for the same men were they gathering data for but one organization rather than for the two. The plans for such cooperation were heartily endorsed by the Chancellor of the University and by the Board of Irrigation. I am happy to report after two summers' work that in my judgment each organization secured data for itself at but little if any more than half the actual outlay which would have been required had each organization been working independently of the other. For each of the two summers eleven hundred dollars were spent for field expenses, about equally borne by the two organizations.

In conducting the field investigations it was thought best to provide the different parties with wagons, teams, and cooking utensils, so that their work would not be hindered by the long distances between points where hotel accommodations are available. In 1895 two such outfits were used, while in 1896 three were likewise employed. The assistants were principally students of the State University, young men well trained for such work. They were placed in the field with instructions to cover certain areas and to make certain observations, which were to be properly recorded in note book and on map, so that a full report of the same could be prepared in the laboratory after leaving the field. How well the work was performed may be judged from the following Report. During 1895 five such assistants were placed in the field, who devoted their whole time to investigations west of the 98th meridian. During 1896 eight assistants were likewise assigned to territory west of the 98th meridian, while three others, working in the southern part of the state for the University, made many observations which have important bearings on the water problem, particularly south of the Arkansas river, both east and west of the 98th meridian. During the field seasons the writer spent the whole time in the field superintending the work of the assistants and making individual observations. The former required a great deal of time and traveling, as it was necessary to visit the different parties as frequently as possible to learn with what success they were prosecuting their work, and to correlate the results obtained by the different parties as the work progressed, so that future labors by each party might be modified more or less by the discoveries already made by others. This was found to be an exceedingly laborious task and required a great expenditure of energy. During the summer of 1895 at least fifteen thousand miles were traveled in connection with this work. In 1896 it was possible to make the field work a little more systematic in arrangement, and yielded correspondingly better results, due largely to the information gathered during the previous year.

The gentlemen associated with me in 1895 were the following: Mr. George

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I. Adams, now Doctor Adams, of Princeton University, a graduate of the University of Kansas, and his assistant, Mr. J. H. Patton; Mr. W. R. Crane, a graduate of the University of Kansas, and his assistant, Mr. Walter Griffiths, who likewise is a graduate of the University; and Mr. W. N. Logan, who worked without an assistant. Later in the season Mr. Crane left the work and Mr. B. L. Pampel joined Mr. Griffiths. In addition to these, Dr. S. Z. Sharp, of McPherson College, was engaged during a considerable part of the time in investigating the water properties of the Dakota sandstones in the middle part of the state. During 1896, Doctor Adams was again associated with me, and had for his assistants Mr. Benj. L. Miller and Mr. Percy L. Daniels. Mr. Miller is an undergraduate, and Mr. Daniels is a graduate of the Engineering Department of the University. Mr. Logan worked during a part of the summer, from April to July, having Mr. Alban Stewart for his assistant a part of the time. Later in the season the work was taken up by Mr. W. R. Crane, as Mr. Logan was obliged to leave it. Prof. Chas. S. Prosser, of Union College, Schenectady, N. Y., assisted by Mr. J. W. Beede, of Topeka, and Mr. C. N. Gould, of Winfield, who were working in the central and southern part of the state, more particularly for the University, likewise made many observations on the water problem, the results of which are embodied in this Report.

Special acknowledgments for assistance is made to the members of the Irrigation Board, individually and collectively; to each of the assistants above named; and to many citizens in the western part of the state for their uniform kindness and courtesies.

General Conditions Regulating Underground Water.

(a). *In Humid Countries.*

With but few special exceptions, throughout all the humid parts of the world water can be found everywhere only a few feet below the surface. Could we render the upper portion of the earth transparent it would then be possible to behold the upper water level over a great surface usually continuous in every direction, a surface extending in a general way under all the surface of the ground, but with milder contours and less rugged outlines than the earth surface. This most universal presence of underground water is so common a condition that the masses of population throughout humid countries have come to look upon it as a certainty, and rarely give it any special consideration. In fact, the industries and operations of civilized man are based upon faith in a perpetual continuance of such conditions.

The few instances in which digging will not obtain water can generally be understood with a sufficient knowledge of the underground water conditions. Certain parts of the materials of the earth are relatively impervious to water and will therefore hold but little of it, and will scarcely let water pass through them. Such are the solid beds of clay, masses of limestone or granite or other crystalline rocks without fissures, and beds of solid, compact shales of various kinds. Where such materials exist near the surface, it is frequently difficult to obtain water by digging. In limestone and granite countries, however, the rock is usually so filled with fissures and seams that the surface water can find channels along which it can pass from the loose surface soils above to greater depths below. In countries where these rock abound the water-filled seams become apparent along the rugged bluffs of streams, along the hillsides, and less frequently in the valleys, where the water breaks forth in the form of springs, water which has

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been following such channels or crevices in the solid rock, sometimes for long distances. Beds of clay and clay shales rarely have springs coming from them. They are so plastic and mobile when wet and under high pressure that they are less frequently fissured, and when fissures are once formed their soft and mobile properties cause the fissures to be filled with comparative rapidity, so that the water passages are destroyed. From this and other similar reasons, the beds of clay and shale rarely have any considerable amount of water within them. Almost invariably throughout the world where heavy beds of shale exist they form a barrier to the movements of underground water.

Many instances in mining localities in different parts of the world might be cited to illustrate this, but perhaps two will be sufficient. In the Indiana oil and gas fields, particularly in the vicinity of Kokomo, drilling for gas has shown that throughout the first few hundred feet below the surface water is relatively abundant. Below this a compact shale bed is reached, 200 or 300 feet in thickness, which has so little water within it that it is necessary to add water in drilling operations. Below the shale beds a porous rock is reached which carries large quantities of underground water. Here, although the water found above is pressing downward upon the shale bed with an average pressure of more than 100 pounds to the square inch, so little water penetrates the shale that none whatever is available from within it. In mining for rock salt at Lyons, Kas., the first few hundred feet of surface material is relatively open and porous, and is saturated with water, large quantities of which are available when wells are sunk to a sufficient depth. In sinking the shafts in salt-mining operations, at the depth of about 300 feet fine-grained, compact shale beds were reached that extended down to the salt, and which entirely stop the downward movement of water. The largest amount of water was found at the contact line between these two formations, or at the upper surface of the shale. When this was successfully cased off the shafting operations were continued downward without any further trouble from water. The salt mines at Lyons have ever since been operated at a depth of about 1,000 feet with no water whatever in the mines, because the heavy beds of shale above entirely prevent the water from passing downward.

(b). *In Arid and Semi-Arid Countries.*

In arid and semi-arid countries the rainfall being much less than in humid countries, the underground water is correspondingly less, provided the geologic conditions do not chance to be especially favorable to the conservation of the small amount of precipitation. Where the geologic conditions are unfavorable one rarely obtains water in any considerable quantity by digging. It sometimes happens, though, that the geologic formations in arid countries are most favorable for preserving the rainfall. This is true to so great an extent in many parts of mountainous countries, and frequently on the great plains, that instead of there being a scarcity of available well water there is actually a larger amount than in the ordinary humid country. If the surface material is loose and porous, consisting principally of sand and gravel and clays, and if the surface mantle rests upon an impervious floor, such as a bed of shale or of compact and unfractured limestone, we have favorable conditions for absorbing and holding whatever water may be precipitated. The dry and porous surface will readily absorb the rain. But as the water works downward it soon comes in contact with the impervious floor, and consequently cannot go further. If, then, the surface of the floor is not too steeply inclined, the conditions are favorable for the accumulation of large quantities of water in the porous material above, which serves as a great reservoir for the water. All that is necessary to obtain water by digging,

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under such conditions, is to sink the well to a depth below the upper surface of the water thus accumulated.

Fortunately the greater portion of the vast plains lying east of the Rocky mountains and extending north and south from Mexico into Canada possesses the qualities just described, and as a result water can be found in more or less abundance by digging throughout the whole plains area. In many parts of mountainous countries similar conditions obtain. A valley is partially filled with the loose detrital material obtained from the decay of the mountain side. Such accumulated products absorb the water from the scanty rains and melting snows with great readiness and hold it concealed beneath the surface so that evaporation has little effect upon it. Often the valley has an impervious floor which will arrest the water in its downward movement and cause it to be held in place, or allow it to gradually work its way down the valley through the porous material, and burst forth at some point below in the form of mountain springs.

Here also in the arid countries the geologic conditions of the area considered are of great importance—even greater than in humid countries where the precipitation is so much more abundant.

An intelligent study of underground water therefore requires an intimate knowledge of the geology of the country in which water is expected to be found. This brings the subject into the domains of geology. Water is as truly a geologic product, and is governed as extensively by geologic conditions as is any other material obtained by mining, such as coal, oil, gas, and the various metalliferous products. In studying the water problem of Kansas, therefore, we must first study the general geology of the state.

Outlines of Kansas Geology.

In Kansas we have a great diversity of conditions. In the eastern part of the state the whole country is composed of limestones, sandstones and shales, with their products of decomposition. Farther west, in the vicinity of Salina and Ellsworth, the Dakota formations, principally sandstones, cover the entire surface of the country. West of these we have another formation, the Benton, consisting principally of limestones and shales, above which lie the Niobrara chalk beds, and the Fort Pierre shales still above them. On top of all these, over large parts of the west, a mantle of varying thickness of sand, gravel and clay was spread during Tertiary time. The surface conditions of the state as a whole, therefore, are exceedingly varied, and the properties of the different formations with reference to absorbing and holding water are likewise greatly diversified.

(a). *The Carboniferous and Permian.*

The eastern fourth of the state is covered by Carboniferous limestones, sandstones, and shales, with the shales greatly predominating, equaling about four fifths of the total thickness. Such shales are almost impervious to water, and rarely produce water in any considerable quantity. The sandstone and limestone beds alternate with the shale beds. The limestone beds usually cover wide areas, reaching an extent of hundreds of miles laterally. Compared with their great lateral extent they are very thin, ranging from 10 feet to 100 feet in thickness. The sandstone beds are much more irregular in lateral extent. They vary in thickness from a few inches to 50 feet or more. Their lateral extent likewise varies from only a few yards to a few miles. Perhaps but few instances can be found in which one individual sandstone bed has a lateral extent in one direction greater than from twenty to forty miles. The shale beds sometimes reach nearly

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300 feet in thickness and extend from north to south across the state, and from the east back to the west as far as we have any knowledge regarding them.

The water obtained by drilling in the shales or deeply buried sandstones almost invariably proves to be salt water. The deep wells at Pittsburg, and possibly in a few other instances, are the only exceptions to this rule known in eastern Kansas. It is therefore useless to hope to obtain a large supply of good water by sinking wells to great depths within the Carboniferous shales or sandstones. But as this part of the state has a copious rainfall good water for domestic purposes is as abundant as is generally found elsewhere. The materials produced by surface decomposition, the clays, the gravels, the sands, form a mantle covering the impervious shales and imbibe the rains and melting snows so freely that water can usually be found anywhere in the east by digging into such materials. Generally it is good, fresh water suitable for domestic purposes. This is particularly true in the northeast part, where the surface has an extra covering of sands and clays and gravels accumulated during glacial time by glacial agencies.

(b). *The Red-Beds.*

Immediately above the Permian over the southern part of the state a mass of clay, shales and sandstones occurs usually known as the Red-Beds, in allusion to their strong brick-red or dark red color. The exact geologic correlation of this formation is a little in doubt. Prosser,* who has recently studied them, correlates them with the Permian. They cover a considerable portion of the state south and west of the Arkansas River. They are immediately overlaid in places by the Comanche, a formation which is so limited in extent in Kansas that it is of no importance in this connection. At other places they are covered by the Tertiary. Here, as elsewhere, the Tertiary is the main water-bearing formation, and therefore the character of the Red-Beds is of considerable importance. The color is due to an excessive amount of red iron oxide which seems to have been accumulated with the clays and sands of which they are composed. Here and there they contain heavy deposits of gypsum, such as the Medicine Lodge gypsum, and are always more or less mineralized with salt and magnesium sulphate and other products of ocean water. It therefore seems that they were laid down in a water which at one time was ocean water, but which by some movement of the earth was shut off from the ocean and evaporated to so great an extent that the water became unusually strongly mineralized. The total absence of fossils within the Red-Beds of the state implies the same origin, as it is probable the water was so saturated that no form of life could exist within it.

The character of the materials constituting the Red-Beds is such that they are exceedingly compact and fine-grained, proper conditions for preventing the percolation of water through them. We therefore have no reason for hoping a well put down in the Red-Beds would produce water in any considerable quantity. Soluble mineral matter is so abundant within them that should one find small quantities of water it would be so highly mineralized, and particularly it would carry so much salt, that it would be entirely unfit for domestic purposes.

The thickness of the Red-Beds in the eastern part of the territory under consideration is not very great; in fact, the beds gradually thin on the east before the Arkansas river is reached. Westward they thicken to an unknown extent. In Meade county it is quite probable they have a thickness of from 1,000 to 1,200 feet, although no authentic well record is preserved showing what their total thickness is.

*C. S. Prosser, University Geological Survey of Kansas, vol. II.

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From the description of the Permian already given it will be seen that the rocks immediately below the Red-Beds have no favorable water qualities. If one should be drilling for water, therefore, anywhere in the southwestern part of the state, and should strike the Red-Beds, from every standpoint it is desirable for operations to cease. The Red-Beds will probably furnish him little if any water. Below them we have the Permian shales, which likewise would furnish but little if any water unless some sandstone stratum should happen to be reached. Should water be found in either one of the formations it is almost certain to be so charged with salt and other mineral material that it would be unfit for domestic use.

(c). *The Dakota.*

The Dakota formation in Kansas covers a considerable proportion of the surface throughout the central part of the state. It is most prominent in the vicinity of Washington, Cloud, Ottawa, Saline, Russell, Ellsworth, McPherson, Rice and Pawnee counties, although lesser areas are found elsewhere. It extends westward, probably underlying the whole of the western part of the state. It reaches far beyond the limits of Kansas. Northward it is known to reach the British possessions, and southward it extends to New Mexico and Texas. Westward it reaches to the foothills area of the Rocky mountains. It is only occasionally exposed at the surface throughout this entire distance, but generally is covered to varying depths by overlying formations.

In character the materials of the Dakota vary between different kinds of shale and sandstone. As the latter is usually the most prominent feature of the formation it is frequently spoken of simply as the Dakota sandstone, although perhaps nowhere could there be found an entire absence of shale. Generally there are from two to four beds of sandstone separated from each other by intervening beds of shale.

The character of the sandstone is remarkably uniform, especially so when we consider that it covers so wide an area. The sand grains in it vary from one-eighth of an inch to perhaps one-thousandth of an inch in diameter, with occasional individuals outside of these extremes. But in most places the grains are remarkably even in size, producing a sandstone of medium texture. But little foreign material is found associated with the quartz sand. As far as yet discovered no grains of feldspar have been found. The cementing material which holds the sand grains together is usually present in limited quantity, leaving an unusually porous rock. This is a point of great practical value, for it allows the sandstone to have a capacity for holding and transmitting much larger quantities of water than would be possible were the little openings between the grains of sand more nearly filled by cement.

The Dakota sandstone where exposed to the surface in Kansas is always highly colored with brown iron oxide. The intensity of the color varies from place to place with the varying amount of iron oxide, but this is always present in sufficient quantities to produce a strong color. Beyond the limits of Kansas the same coloring matter is frequently found, particularly in the Dakotas. Westward in Colorado it is less abundant. In fact the Dakota sandstone of eastern Colorado is no more highly colored than ordinary sandstone.

The Dakota formation is one of the most important water-bearing terranes in America. Having so wide a geographic extent it exists in different parts of the

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country under varying climatic conditions. In general, it is true, it occurs only in arid, or semi-arid parts of America, but with all this it is possible for it to gather large quantities of water from rainfall and melting snows, and from streams which flow over it. Its porosity underground seems to be about the same as that above ground, so that the movement of water from place to place within it is entirely independent of mere accidental surface exposure. In localities where it is covered several hundred feet deep by impervious layers, so that a head or pressure can be produced by an eastward movement of water within it, such pressure is sure to follow. As a result of this, when reached by the drill in well boring there is always an upward movement of water in the well. In many parts of America this is sufficiently strong to produce a strong artesian flow, while elsewhere the pressure is so limited a flow from the surface is not obtained. Perhaps the greatest pressure thus far discovered in this sandstone is in North and South Dakota. Here at places the pressure equals four hundred pounds to the square inch. In eastern Colorado and western Kansas artesian wells obtained from this source are by no means rare. It is probable that water can be obtained anywhere in the state in localities where the Dakota sandstone is covered by an impervious layer sufficient to prevent too great a loss by seepage.

The accompanying geological map, Plate XXIII, is marked with the areas over which the Dakota is exposed at the surface. The reader may place great faith in the statement that it underlies practically all the territory to the west of these exposures, and that it may be reached by drilling, and that water may be obtained from it.

(d). *The Benton.*

The Benton formation immediately overlies the Dakota, and reaches a thickness of about 400 feet. Its surface exposures are represented on the geological map, to which the reader is referred. It reaches westward and northward beyond the areas where it is exposed at the surface, so that a well drilled at any point to the northwest beyond such limits would penetrate it if carried sufficiently deep, and would pass through about 400 feet of the Benton before reaching the Dakota. The Benton likewise has a great lateral extent, reaching north and south and west perhaps as far as the Dakota itself, as already described.

The Benton is composed of alternating beds of shale and limestone, with the shale greatly predominating. The uppermost part of the formation is shale, below which a number of thin beds of limestone are found, separated from each other by thin beds of shale. These limestone layers frequently are no more than 12 inches thick, yet they have a lateral extent almost as great as the Benton formation itself. One of these layers is particularly noteworthy. It is quarried from the north side of the state to the Arkansas river, and used for fence posts, and is hence generally called the post-stone. In traveling over the country one can always recognize his proximity to outcroppings of this limestone by the frequency of the stone fence posts. Sometimes they are hauled for distances of from 5 to 10 miles, so that finding them in use is but little indication that the fence-post layer may be found at any particular place. Above the fence-post limestone horizon the greater part of the Benton is a black or dark blue shale. Here and there traces of limestone occur within it and marine invertebrate fossils, particularly at certain horizons.

At the summit of the Benton, imbedded in the black shale, concretionary masses of calcite colored brown with impurities occur in great abundance. They are oval in shape and sometimes reach the large size of from 6 to 10 feet in diameter. On the prairies where this particular horizon is exposed at the surface, these concretions produce a unique appearance in the landscape, often recalling

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the shocks of hay in a meadow. On account of their color being so similar to ordinary zinc blend, the most common ore of zinc, different parties at many places in the state have mistaken them for zinc ore.

It will be seen from the foregoing description of the Benton that no one need reasonably expect any considerable amount of water to be found anywhere within the entire 400 feet of the formation. No shale beds in the state are known which are more nearly impervious to water than are these Benton shales. In some places they are exceedingly bituminous, so much so, in fact, that they emit a strong odor of petroleum, and are reported to contain enough oil to burn when properly handled. This supply of carbonaceous material would make them all the more impervious to water, and would correspondingly decrease the probabilities of finding water in them. Further, they are known to be partially saturated with salt. In certain parts of the state salt marshes exist which seem to get their salt partly from the Benton shales, although possibly some of the salt comes from the Dakota shales.

(e). *The Niobrara.*

Above the Benton formation lies the Niobrara, which is exposed along a relatively narrow strip just west of the Benton, reaching from Jewell county to Hamilton county, on the western border of the state. As far as we now know none of the Niobrara exists in the state south of the Arkansas river.

In character the Niobrara is principally a limestone of a chalk-like nature, the chalk of Kansas being confined entirely to the Niobrara. Chalk beds immediately overlie the concretionary shales of the upper Benton, above which is a mass of shale from 20 to 40 feet thick. This shale is a dark blue on fresh surfaces, but upon exposure weathers into a chalk-looking material which in many respects resembles chalk itself. Above the shale-like beds is another mass of chalk. The whole of the Niobrara formation in Kansas equals about 400 feet in thickness at places where it is exposed to the surface. Gilbert* gives a much greater thickness for the Niobrara where exposed in Colorado. We may therefore conclude that it appreciably thickens westward. This is a point of considerable importance, for it increases the depth one would have to drill in order to reach the Dakota sandstone.

The Niobrara is no more of a water-bearing formation than the Benton is. In fact, the great chalk beds are as nearly entirely free from water as any formation known. No encouragement can be given, therefore, for expecting water from within them. If a driller penetrates the Niobrara chalk work should be suspended at once unless the intention is to pass through both the Niobrara and the Benton and to reach the Dakota sandstone below.

(f). *The Fort Pierre.*

In the extreme northwestern part of the state a still higher member of the Cretaceous is found, the Fort Pierre. This is exposed to the surface over such a small area that it can hardly be recognized on a geologic map drawn to the scale of the accompanying one. It is found along the upper waters of the tributaries of the Republican in the extreme northwestern part of the state.

The Fort Pierre consists of heavy, dark-colored shales, with only a small amount of calcareous material here and there in it. As far as we now know these shales are about 100 feet in maximum thickness within the state, although it is well known that they increase greatly in thickness in Colorado to the west.

The Fort Pierre, like the Niobrara and the Benton, is a formation entirely

* Loc. cit., p. 16.

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void of water. We have therefore a mass of Cretaceous shales and limestones aggregating between 800 and 900 feet in thickness, throughout all of which there is practically no water whatever to be obtained. The character of all this material is such that it is practically impervious to water. Therefore in their western extent they form an impervious floor upon which the water-bearing Tertiary material is laid down. Any one searching for water in any part of western Kansas can recognize these formations when reached by the drill. The Tertiary material above, the water-bearing material, is so different in character from the Cretaceous floor that no difficulty can be experienced by any one in distinguishing between them. The well drillers over the state have already learned to recognize this difference, and from a somewhat costly experience they have likewise learned the uselessness of searching for water anywhere within the Fort Pierre, the Niobrara, or the Benton formations. The advice therefore should be emphatic that when the drill reaches the uppermost of these horizons all drilling should cease unless it is intended to pass through the barren strata and draw water from the Dakota sandstone.

(g). *The Tertiary and Pleistocene.**

Overlying a large part of the western half of Kansas, aggregating in fact nearly two-fifths of the entire area of the state, we find a thin mantle of sand and clay and gravel, with a maximum thickness of about 350 feet, which from paleontological evidence is known to be Tertiary and Pleistocene in age. The material is surprisingly regular when considered in a general way. It is essentially the same in the north part of the state as in the south. It is so nearly identical in general appearance and character of composition that one soon learns to recognize it anywhere it may be seen. If considered in more detail, however, great differences will be found. The sand varies from exceedingly fine sand to coarse sand or gravel. The gravel varies from a coarse sand to pebbles from 4 to 5 inches in diameter. The clay in places is almost pure clay, having a high grade of plasticity. Elsewhere it is intimately mixed with a fine sand of uniform grains, reproducing in every respect deposits similar to the glacial loess deposits so abundant farther east and northeast.

In mode of arrangement there is great irregularity, yet an approach to regularity. In general the clay is found on top, immediately at the surface and has been called the plains marl. This is not always true however, for in many localities the surface to a depth of from 20 to 40 feet is occupied by sand with but little clay intermingled, while clay is liable to be found at any depth below the surface. The sand beds are irregular in distribution. Sometimes they consist of heavy beds of relatively great thickness; elsewhere they are in thin beds with clay beds or gravel beds interspersed. The gravel beds likewise are unevenly distributed, occurring frequently at the base of the Tertiary, but almost as frequently at intermediate horizons, and not at all rarely at the surface. These are the more commonly noted positions in which the different beds of material are found. It should be understood, however, that in places there is the greatest irregularity. Clay beds lenticular in shape, varying in thickness from 5 to 100 feet, are liable to be met with at any place. Gravel beds of like irregularity of thickness and outline are known, while sand beds occur here and there at times in as irregular a manner as could well be imangined.

Another feature of the Tertiary deposits which is very characteristic is the

*As the Tertiary of these deposits grades into the Pleistocene on the surface, no attempt is here made to distinguish between them, as they are both equally water-bearing.

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great abundance of calcium carbonate found within them. During the preparation for exhibition of the materials obtained from the different state wells it was found that in every instance each sample of the material which came from a depth of more than 5 or 6 feet below the surface had a sufficient amount of calcium carbonate in it to cause it to effervesce strongly when treated with an acid. This calcium carbonate is present in great quantities in places, and cements the sands and gravel so strongly that a firm rock is occasionally produced. Such beds resist erosion much better than uncemented beds of clays and finer sands. As a result of this they are usually prominent along the bluffs of the various rivers and lesser streams. This is true to so great an extent that one can scarcely travel ten or twenty miles in any direction without observing them, excepting he chooses his journey on the high and unbroken uplands. See plate VI.

Such an accumulation of sand and gravel of various degrees of coarseness cemented together in the way indicated has been named the mortar beds, and are known in geologic literature by this designation. The mortar beds formations have sometimes been described as occurring near the bottom of the Tertiary. Our observations in Kansas, however, have not substantiated this view. In most localities the most prominent strata, the mortar beds, are far removed from the Cretaceous floor beneath. This is true in so great a majority of cases that few instances are known in which the mortar beds rest entirely on the Cretaceous. Almost every stream whether large or small throughout the whole Tertiary area of the state has the mortar beds exposed, generally on the uppermost part of the material of the bluff. This is notably so along the north bank of the Arkansas river from Garden City to Dodge City, along the banks of the Saw-Log and Buckner to the north of Dodge, along the bluffs of the Prairie Dog throughout its course in the Tertiary, along the high uplands on either side of the Saline river, and preeminently along Crooked creek and the Cimarron river in Meade and Seward counties. At Arkalon the river channel is cut down into the Tertiary nearly 200 feet. The mortar beds are very prominent near the upper level of the bluffs, and are scarcely to be noted lower down. Frequently two or more strata of the mortar beds will be found in one individual bluff separated from each other by layers of exceedingly fine sand mixed with clay.

The records also of the different state wells which have been drilled confirm the view that the mortar beds occur irregularly, rather than immediately above the Cretaceous. The materials from these wells have been studied with great care and in not a single instance was the ground water found within the mortar beds. The sand and the gravel carrying the water seem not to be cemented by the calcium carbonate. For a full discussion of the physical properties of the Tertiary, the reader is referred to the article on the Tertiary in Volume II. of the University Geological Survey of Kansas.

The character of the Tertiary material is most favorable for the absorption of water. Almost everywhere the surface conditions are such that rain is readily absorbed. It is this property in connection with the impervious underlying Cretaceous floor which has made it possible for such vast quantities of underground water to exist on the great plains. The rains and snows are largely absorbed by the Tertiary material, but the impervious Cretaceous floor prevents the downward movement of the water and permits it to accumulate in the lower parts of the Tertiary just above the surface of the Cretaceous.

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Character of the Floor.

As has already been stated, the formation lying first beneath the Tertiary sands and gravel serves as a floor for the Tertiary water to rest upon. Without this we would have but little chance to find an accumulation of water on the great plains. It is therefore important to study the floor in this connection. From the foregoing description it will be seen that could the thin mantle of Tertiary be removed the upper surface of the ground at one place would be the rocks of one formation, and in another those of a different formation. The floor underlying the Tertiary, therefore, is not alike in all places, but with the exception of a few small areas where the Tertiary rests upon the Dakota, this floor is about equally impervious. In the northwestern part of the state where it rests upon the Fort Pierre shales, and a little farther to the east, where it lies upon the Niobrara, or farther east still, where it rests upon the Benton, or to the southeast, where it rests upon the Red-Beds, in all these places the floor is practically impervious to water.

There are good reasons for believing that before the Tertiary materials were deposited the plains area was lifted into dry land and subjected to the weathering agencies of the atmosphere, the rains and the snows, the freezes and thaws, and that as a result the surface was worn into hills and hollows corresponding in general appearance with the surface of the land at the present time. Such irregularities produced in this way were covered by the Tertiary materials. It must follow from this that underneath the Tertiary such irregularities exist in the floor upon which the ground water now rests. No one can determine the exact character of the floor in any one locality, unless there are some special surface indications regarding it, without exploring with the drill. We know that the general inclination of the floor is eastward at an angle upon the average about the same as the inclination of the land surface. For example, the Tertiary covering has about the same thickness in Cheyenne county that it has in Stafford county. Now the general elevation of the surface in Cheyenne county is about 3,300 feet above sea level, while that of Stafford county is less than 2,000. The surface of the underground floor therefore must decline 1,300 feet in this distance, corresponding with the general inclination of the country. In some places the inclination of the floor is greater than in others. Through the western 100 miles of the state it will average from 7 to 8 feet to the mile eastward. Here and there local variations occur causing the maximum variation to be to the northeast, or southeast, or some other direction at a greatly increasing angle. In the southwestern part of Clark county, for example, the inclination southward from near Minneola to the south line of the state is close to 20 feet to the mile, and in some places is even more than 30 feet to the mile. Likewise, along the south line of the state in Meade county the inclination eastward is more than 20 feet to the mile. These high angles, however, are unusual and do not by any means represent the average. Still it is probable that there are many places through the state where the upper surface of the floor has local inclinations fully as great and probably even greater.

Such considerations as these are of the greatest importance in connection with the study of the underground water of the west. A hole may be put down in one place and find no water whatever, the drill penetrating the floor on one of the upper ridges at a point above the upper surface of the water level. Possibly half a mile, or a quarter of a mile, or even less distance away a hole might be drilled so that the floor would not be reached until after the water level was passed. It would therefore furnish an abundance of water. Many instances are known in which wells have proved entirely barren, while other wells less than a hundred yards away have been productive of good and wholesome water. Such

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conditions are easily understood from the foregoing explanation. The great difficulty in predicting where water can be found and where not lies in our slight knowledge of the details of the irregularities in the surface of the underground floor. Any one with ordinary ability for accurate observation can make a survey of his premises and determine closely the conditions of the floor as regards its irregularities. If a ravine or a creek has cut entirely through the Tertiary, and has exposed the limestone or shale along the bluffs, it is certain that the floor has been reached. The probabilities are, therefore, that the same materials extend outwards from the creek and underlie the Tertiary at no considerable depth.

A good illustration of this is found north of Dodge City. The little creek called the Saw Log along a part of its course has cut through the Tertiary and exposed the Cretaceous along its bluffs. Westward a point is reached where the erosive processes of the stream have not reached the Cretaceous floor, but over a considerable area reaching westward more than two miles drilling has shown that the Cretaceous floor is near the surface, and probably exists in the form of a gentle ridge, so that no water is found above it. Wells put down in this particular locality strike the shale before water is reached, while either to the north or south water can be found in great abundance.

The conditions in Cheyenne county are similar. The tributaries to the Republican have cut their way through the Tertiary into the Fort Pierre shales in a few places. Of course no water can be found by drilling in those shales. However, many wells have been started in the Tertiary with apparently good reasons for expecting water could be found. But upon sinking only a limited distance the drill would strike the Fort Pierre shales, when all hope of finding water would therefore have to be abandoned. Another good illustration of this is in the town of Stockton, Rooks county. Here the valley of the North Solomon has been cut down into the Niobrara chalk for 100 feet or more. Subsequently a filling in process occurred until the valley was filled to a depth of from 30 to 50 feet, producing a broad level surface over which the river flows as it now exists. Well drilling on the different lots in Stockton yields varying results. In one part of the town water can be found in great abundance. In another part, however, water is not found, but in its stead the chalk is reached at a depth less than that at which water is found on adjoining lots. The explanation is easily understood. An underground ridge of the chalk beds extends outward into the valley some distance, a ridge similar to that which we so often see along the valleys at the present time. The old Solomon river valley is filled with water to a certain level. A well drilled in it at any point where the water level covers the chalk bed floor will find an abundance of water. But should the drill be started over one of these chalk ridges which extends down into the valley so that the surface of the chalk is higher than the underground water level, of course no water could be found.

These illustrations are sufficient to show the importance of a careful study of the character of the underground floor, the impervious floor upon which the Tertiary waters and the Tertiary material rest. No one phase of the geology of the western part of Kansas is of more practical importance to those seeking for water.

Classes of Underground Water.

In the discussion of underground waters on the plains, it is well to bear in mind the different conditions under which water exists, and the different classes into which the underground waters may be divided with reference to the geologic character of the materials in which they are found. Geologically we have two great classes of water. One exists in the Dakota sandstone. It probably has a

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slow movement eastward, has principally been gathered from the rains falling in the eastern part of Colorado and farther to the north over areas where the Dakota sandstone is exposed to the surface, and in its eastward movement passes underneath the Benton and Niobrara and superior Cretaceous formations, so that in most places it exists under a pressure sufficient to cause it to rise an appreciable distance above the level at which it is found by the drill, giving artesian wells, or wells decidedly artesian in character.

The other water is that which is commonly known as underground water, sheet water, or underflow, as these expressions are understood by the citizens of western Kansas. It is confined to the Tertiary sands and gravel. It lies immediately above the impervious Cretaceous or Red-Beds floor, and is sufficient in quantity to more than saturate the materials in which it exists for a distance above the floor varying from 5 feet to more than 100 feet. Throughout the greater part of the plains area, therefore, these two classes of water are separated from each other by all of the Benton and higher Cretaceous deposits. In rare cases, however, the Tertiary rests immediately on the Dakota sands, permitting the Tertiary water and the Dakota water to commingle. Could we exhaust the supply of either one to an appreciable degree, the other would doubtless be drawn upon and a movement would be set up from one into the other. Still, for convenience of discussion and clear presentation of the water conditions, it is desirable that the two classes should be discussed separately.

WATER IN THE DAKOTA SANDSTONE.

The Dakota formation consists largely of beds of sandstone aggregating a thickness of from 200 to 700 feet. The sand grains in this sandstone are generally but poorly cemented together, leaving spaces between them which may well serve as receptacles for water. The Dakota sandstone covers the greater part of the plains area from the British possessions on the north to Texas on the south. Throughout this entire distance, it extends westward to the mountainous area, lapping up on the foothills along the eastward slope of the Rocky mountains, or capping the ridge generally known as the "Hogback," lying just east of the mountains in Colorado, as has been so well shown by Gilbert in his recent article on water conditions in eastern Colorado.

Professor Todd * has recently estimated that the Dakota is exposed to the surface over not less than three thousand square miles between the north line of Colorado and the Canadian boundary. Mr. Gilbert † mentions a number of places in Colorado where the Dakota is similarly exposed, all of which he thinks will aggregate from sixteen hundred to seventeen hundred square miles. These estimates for local areas by no means include all the surface exposures. We have also a very considerable increase directly from streams. At the Great Falls of the Missouri in Montana, Colonel Nettleton has estimated that as much as 834 cubic feet of water per second, or about 1,673 acre feet per day, is lost by the river. It is probable that all or nearly all of this vast amount enters the Dakota sandstone. The North Platte river, the Big Horn, the Yellowstone, and other streams likewise cross the Dakota and evidently supply it with large quantities of water. In addition to all this there are areas where the Dakota is immediately overlain by the Tertiary. How extensive the contact is between these two for-

* Wind and Water, Vol. I, p. 178.

† Loc. cit., p. 32.

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mations no one can even give an approximation. It is certain in Kansas that in two or three places such a contact exists, and that the general Tertiary underground water has an opportunity to be absorbed by the Dakota sandstone. We may reasonably suppose that like areas exist in many places over the great plains. The result of this would be to produce an interchange of water between the two, so that there would be a movement in whatever direction the forces governing the flow would determine. This adds vastly to the possibilities of water in the Dakota, for it so greatly increases the gathering ground from which water may be derived.

It may well be asked what becomes of this large amount of water imbibed by the Dakota sandstone. The answer is easily given. It should be remembered that the area covered by the Dakota sandstone is exceedingly great, being nearly five hundred miles in width and about three times as long. The opportunities for leakage over this large area cannot be calculated, for no one knows the details of the formations both above and below the Dakota sufficiently to give any rational estimate of where and how much leakage will take place. In many places we know that springs occur, particularly in those places where the Dakota is exposed directly to the surface, such springs being wholly or partially sustained by the waters imbibed far to the west. The remainder of the water taken in by the Dakota is held within its volume at the present time and, in general, may everywhere be rendered available by drilling into it.

We therefore have a great geologic formation covering many thousands of square miles, which is a continuous underground sheet for thousands of miles in extent, and which has been imbibing water from the rains and snows perhaps for thousands of centuries. It has thus become a great underground reservoir filled with water, the leaks from which are known in the form of springs and seeps along its eastern borders in many places where it is brought to the surface, and along the banks of streams which have cut their channels downward until the Dakota has been reached.

In a general way it may safely be said that all that is necessary to obtain water on the great plains is to penetrate the Dakota sandstone. This proposition, although true in a general way, may not be verified in every instance. It is reasonable to suppose that a rock mass covering so wide an area is not perfectly uniform throughout. Here and there may be areas where the cementing material is more abundant than ordinarily, or where the grains of sand are finer, or where the sand beds in their original form had silt and clay intermingled to a sufficient extent to produce a relatively impervious mass. We know, in part, that such conditions obtain at irregular intervals, and that consequently a drill hole made in such a place will yield but little if any water; not because the great Dakota beds were not reached, but because they were reached at a place where the open spaces between the sand grains had been filled with clay, or mud, or cementing material, so that water could scarcely flow through.

The conditions governing artesian wells are so generally known by all classes of people at the present time that it would seem unnecessary to devote space to a discussion of the general principles regarding them. All that is necessary is to have a water-bearing stratum closed both above and below by an impervious layer, the water-bearing stratum to be so arranged that at places within it the movement of the water is retarded by one cause or another so that a pressure, or head, is established. The ideal way to establish such a pressure is to have the stratum occupy a trough, or valley, with its

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extremities on either side being higher than the valley. This condition is not necessary, neither does it obtain in any considerable extent on the great plains. If the water-bearing stratum has unequal degrees of porosity throughout it, or if it is greatly thickened over its gathering areas, or thinned in the opposite direction, a retarding of the movement of the water within it would produce a head so that artesian effects would result. This latter condition is the one which makes it possible for the Dakota formation to give artesian water. Along its western extremities it will average from 4,000 to 6,000 feet above the sea level, while along its eastern limits its elevation is from 1,200 to 1,800 feet. Such a difference in elevation would produce a water pressure sufficient to raise a stream of water in the eastern part more than 1,000 feet high, were it not that the leaks are so great the pressure is kept down.

The conditions of the Dakota sandstone may be illustrated by a pipe filled with sand into which water is being poured as rapidly as the sand at the receiving end can receive it. Suppose this pipe is inclined at a gentle angle. The water will flow from the higher end to the lower. If the diameter is constant throughout and the character of the sand filling is constant, the water will flow as rapidly in one place as in another, and therefore its movement will correspond to water in an open trough. But if the diameter were restricted at different places, or if the sand filling were made finer at one place than another, there would be produced certain points through which the water would have to travel more slowly than the possibilities in other parts. In this way above such points of retardation of movement a pressure would be set up. Should the pipe be tapped above such a place the pressure would be sufficient to cause the water to flow upwards in a stream corresponding to an artesian well.

The Dakota sandstone has no place within it where the movement is entirely stopped, but the strata vary in thickness, pinching out at places to half or a third the thickness elsewhere. We may reasonably suppose, also, that the cementing materials are much more abundant in some places than in others, and that the spaces between the sand grains are correspondingly filled with the cementing material to different degrees, so that the amount of water which can pass a given point at a given time is variable, but that nowhere is it entirely shut out.

Experience in drilling for water in the Dakotas, in Nebraska, in Colorado, in Kansas and elsewhere abundantly verifies the conclusions just given, that in a general way one may confidently expect to obtain water in large supplies wherever his drill penetrates the Dakota sandstone. Artesian water has been found in all of these states in Tertiary or Pleistocene formations, so that the reader should not assume from what has been said that all the artesian water in them is obtained from the Dakota. Yet throughout the whole plains area in general the Dakota sandstone is the principal artesian formation. In Minnesota, in the Red river valley the artesian water is principally found in the Pleistocene, likewise in North Dakota the Pleistocene formations furnish artesian water in Richland, Cass, Traill, Grand Forks, and other counties. But the most substantial wells of the Dakotas and Minnesota are from the Dakota sandstone. In the Dakotas the principal wells are at Vermillion, Yankton, Tindale, Mitchell, Plankinton, Kimball, Chamberlain, Letcher, Woonsockey, Artesian City, Vilas, Huron, Brookings, Miller, Highmore, Harold, Hitchcock, Redhill, Frankfort, Greensburg, Ashton, Andover, Aberdeen, Columbia, Ipswich, Ellendale, Jamestown, and Devil's Lake, all of which draw water from the Dakota sandstone.

The artesian wells of eastern Colorado almost all come from the Dakota sandstone. This is true of all those along the Arkansas river valley from Cañon City

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to the Kansas state line. The depth at which the water is found varies greatly. In some places it is but a few hundred feet, in others it is more than a thousand. The amount of water obtained from artesian wells in Colorado at the present time is not very great, but many times the total production of Kansas. The best wells perhaps are found at Rocky Ford and vicinity, at which place one well is reported * to yield 156 gallons per minute, a second well, 68 gallons per minute, and a third well, 60 gallons per minute, which makes them much stronger than any wells in Kansas.

In Kansas all of the artesian waters in the western part of the state, excepting those of Meade county, are from the Dakota sandstone. Thus far the best flow has been found in the vicinity of Coolidge. Quite a number of wells have been drilled here, each of which obtained a good flow provided it was properly cased. Many of such wells have stopped flowing. A slight investigation of the matter convinced the writer that the cause was a destruction of the casing by corrosion. The common ground water in the river valley at this place is found at from 6 to 12 feet below the surface. Were an artesian well drilled and not cased the artesian water would evidently rise to a point where it could spread laterally, and no further. Such a point would be found where it reached the level of the underground water in the river valley. The casing which was employed for these wells at Coolidge was usually made of galvanized sheet iron. It required but a few years' time for such casing to become corroded so that it leaked and allowed the artesian water to spread laterally the same as though no casing was employed. In every instance noted the flow has been obtained uninterrupted providing the well was cased with heavy iron piping when it was drilled.

The strongest well known in this locality at present is one owned by Mr. Nolan, south of the river and about two miles and a half southeast of Coolidge. It has a flow of fully fifty gallons per minute. The wells drilled by Mr. Peck, and used to supply the water system of the city of Coolidge, are still flowing as copiously as when first drilled. At present pumps are attached which are operated by steam power to lift the water to the water tower. The pumps draw the water a part of the time directly from the wells, so that during the day a much larger quantity of water is obtained from them than could be by the natural flow. The pumps are usually run for about ten hours each day, at the rate of about 3,600 gallons per hour. This lowers the water within the wells to from 20 to 30 feet. During the fourteen hours interval the supply is again replenished and the flow continued. Almost all the other wells in the vicinity of Coolidge have become choked up in the manner indicated above and consequently have little or no flow. During the past summer Mr. M. Christenson drilled a well in the eastern part of Coolidge on the north side of the river. At a depth of 210 feet he obtained a strong flow which, although not measured, has been described as fully equaling the flow of the Nolan well.

Eastward along the river the wells at Syracuse have penetrated the Dakota sandstone and obtained what seemed to be large quantities of water. None of these, however, have been cased properly to determine whether or not the water would rise above the surface. The probabilities are that should they be properly cased artesian water could likewise be found at Syracuse and at places farther east.

At Garden City a deep well was put down during the summer of 1888. It passed through the Dakota sandstone and is reported to have furnished large

*Gilbert, loc. cit., p. 34.

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quantities of water. At that time, however, those drilling the well were not interested in the water found, consequently no attempt was made to case the well so that it would flow to the surface. We are therefore in ignorance of the exact conditions of the artesian flow at that place.

A deep well was drilled at Larned some years ago which is reported to have obtained a good flow from the Dakota. As the proprietor was wanting a mineral water the Dakota water was cased off and the well continued to a depth of 750 feet, at which point a highly saline water was obtained. A deep well was likewise put down at Great Bend, which obtained water from the Dakota sandstone at a depth of about 344 feet. The well was bored much deeper, but found no water of any consequence.

It is therefore probable that water could be obtained from the Dakota sandstone which would rise to the surface, or nearly to it, throughout the whole of the Arkansas river from Coolidge to Great Bend. Without doubt many valuable artesion wells could be obtained in this valley.

Both north and south from the Arkansas river valley the Dakota sandstone has been reached by numerous wells, all of which obtained large quantities of water. In the vicinity of Ness City different wells carried to a depth of from 250 to 300 feet have obtained water from the Dakota sandstone. No well has yet been drilled in Ness county which obtained a flow at the surface, but in all of them the water would rise to within from 35 to 60 feet of the surface, so that it could easily be pumped.

The Shepherd well, southwest of Ness City (section 25, township 19 north, range 24 east), reached an abundant supply of water at a depth of 300 feet which rose to within 65 feet of the surface. As this is a typical well, its record, although somewhat incomplete, may be given as follows, measuring from the surface downward:

Stratum.	Thickness.		Total depth.
	Feet.	Inches.	Feet.
1. Surface soil and clay	.....	.....	.....
2. Limestone (Fort Benton)	18	.....	.....
3. Thin seam of clay shale	.....	.....	.....
4. Limestone	20	.....	.....
5. Clay (probably clay shale)	.....	.....	.....
6. Limestone	.....	10	.....
7. Clay (probably clay shale)	45	6	.....
8. Limestone	.....	8	.....
9. Shale	54	.....	.....
Total depth to this point	.....	.....	136
10. Record missing	54	.....	190
11. Clay (probably shale)	20	.....	210
12. Coarse loose sandstone (some water)	.....	2.5	.....
13. Blue sandstone	25	.....	235
14. Thin seam of clay (water bearing)	.....	6	.....
From this distance to 300 feet was an alternation of clay shales and sandstone throughout the whole distance, and all was water bearing	.....	.....	300

South of the river the deep well at Santa Fé obtained water from the Dakota sandstone, as did also a number of other wells to the east, in Meade and Ford counties. Invariably the water rose toward the surface. In Morton county at Richfield an artesian well was obtained which draws its water from a depth of 570 feet, from strata which have been called Triassic, but which may be the Dakota.

Follett,* in describing the Santa Fé well, wrote as follows:

"In well 173, 160 feet from the surface, the fine sand gave place to blue clay,

*Follett: Senate Ex. Doc. 41, 52d Cong., 1st Session, Vol. IV, Pt. II, p. 27.

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which lasted for 164 feet, and was underlaid by 13 feet of hard blue limestone The well was first dug for about 180 feet, and then a 2-inch hole was put down. When the drill had passed through the limestone, at a depth of 337 feet below the surface, a strong flow of water quickly came near to the top of the drill hole. When the pump was put on it was found that the pipe was solidly filled with very fine sand. The well was then dug to 240 feet, the hole being three feet square, and another 2-inch hole put down through the limestone. This time the water spouted out of the drill hole so rapidly that it was with difficulty the tools were gotten out of the well. It rose to the level of the water in 172 (which is 200 feet below the surface) and has since remained there, although pumped for town use with steam pump."

Letters have been received from the Hon. A. W. Stubbs, one of the managers of the company, and from J. A. Grayson, who did the drilling, neither of whom could give an exact record of the well, although each gave from memory a record which was essentially the same as this given by Mr. Follett. The 13 feet of hard blue limestone is certainly the Benton limestone, and the strong flow of water which, according to Mr. Grayson, was found in a 20-odd feet layer of "gravel," without doubt came from the Dakota sandstone. This water was good and fresh and was hauled by the wagon load to supply almost every family for miles around. Mr. Stubbs adds further, that the well went on through 250 feet or more of material about which he was in doubt, then through 600 feet of red material which corresponds to the Red-Beds exposed to the surface farther east, and at a depth of about 1,250 feet struck salt water.

The details of this well have thus been given for a number of reasons. First, to establish the reasonable probability of the record which, finding that the original record was lost, some might be inclined to doubt; second, to show that the Dakota sandstone could be reached in Haskell county, and that it would produce an apparently unlimited quantity of good fresh water; and third, to show that there are no reasonable grounds for hoping good water can be obtained at any depth below. Kansas is full of experiment holes the data from which have generally been lost, but which, if saved and properly collated, would be worth hundreds of thousands of dollars to her citizens.

This one well in Haskell county may serve as a type for all southwestern Kansas. In boring for water one need not stop until the Dakota sandstone has been reached and penetrated. But there is no point in the western half of the state at which it would be advisable to go below this terrane in search for water.

Artesian water generally the world over is not sufficiently abundant to be a very important source of water for irrigation purposes. The artesian reservoirs should be looked upon in two ways. First, as a reservoir of water the same as a lake is a reservoir, or as a reservoir artificially prepared. From this view it is important to know the dimensions of the reservoir and the per cent. of the cubical contents which is available water; that is, water which may be obtained from such reservoirs before the supply is exhausted. The second way of looking upon the artesian water reservoirs contemplates the rapidity of the supply of water to the reservoir. This considers the constant addition of water. The available water from this standpoint would never be greater than the natural addition. If we have an addition of water to the Dakota sandstone of so many million cubic feet per year the sum total of leakage through natural springs and artificially prepared wells

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should equal this addition. The resident of the plains country therefore should understand clearly the nature of the supply of water from the Dakota. Doubtless water exists at present in sufficiently large quantities so that many hundred square miles could be irrigated in each of the several states.

If, however, the demand for such water should become so great that it exceeds the annual supply, the reserve quantity of water in the reservoir would be drawn upon. This would result in a diminution of the available water somewhere. It would be noticed first over the areas where the sandstone has the greatest elevation—that is, to the west. As the supply was constantly decreased the area over which the artesian wells could not be obtained would gradually extend itself eastward until, with a sufficiently great use of the water from the sandstone to the east, the whole area would ultimately become exhausted. Of course this is a theoretical consideration, introduced to show the tendencies. No one believes it would be mechanically possible to entirely accomplish this exhaustion. But such would be the tendency. The legitimate use of the underground water, whether artesian or not, is limited to the supply. Any draft upon a reservoir of water, whether a surface lake or an underground lake—any draft upon such bodies of water in excess of the regular supply is not to be encouraged excepting for temporary emergencies. Such a proceeding would correspond to the individual living upon his capital rather than upon the income from the capital.

There is a wide-spread misconception regarding the amount of available artesian water. Such misconception is due largely to a neglect of the principles just explained. When underground water is rapidly drawn upon the supply must necessarily diminish, and the fact that the flow is great at first is no indication whatever that it will continue to be great. A careful study of the catchment areas and the exact supply of water should always be made before any one places much confidence in the permanency of any underground body of water. This subject was very clearly and forcibly presented by Major Powell* to the Committee on Irrigation of the House of Representatives in the spring of 1890, from which statement the following quotations are made, believing that they will be interesting and instructive to the readers of this Report:

ARTESIAN IRRIGATION ON THE GREAT PLAINS.

Artesian reservoirs can never be an important source of water for irrigation. The supply of water thus naturally stored is small. The share of it which agriculture can economically obtain through wells is still smaller. Though irrigation has aided agriculture from the earliest times, and though artesian wells have long been understood, the world has succeeded in using artesian water for agriculture in but a few exceptional spots. The Great Plains may become one of these exceptional localities, but the conditions do not warrant great expectations.

In order to make these propositions clear, it is necessary to give consideration to some of the general facts and principles affecting artesian water supply, to the economic conditions limiting the utilization of artesian water for irrigation, and to the special conditions existing on the Great Plains. A brief account will also be given of such irrigation as is based on artesian water supply in various countries of the world.

GENERAL CONSIDERATIONS AFFECTING ARTESIAN WATER SUPPLY.

An artesian reservoir is usually a bed of sand or sandstone or other porous rock, included between strata of clay or shale or other fine-grained rock through which water cannot freely flow. It is necessary that the porus stratum come to the surface at some point so as to receive a supply of water from rain. If all the points at which it comes to the surface or communi-

*J. W. Powell, Eleventh Annual Report of the Director of the U. S. Geological Survey, Part II., pp. 260 to 275.

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cates freely with the surface lie higher than the point at which water is to be drawn through wells, the reservoir is of a type which may be denominated as perfect; but if the stratum communicates with the surface also at points which lie lower than the point from which boring is made, the reservoir is imperfect. In the case of an imperfect reservoir the possibility of an artesian flow depends upon the resistance opposed by the porous bed to the free flow of water.

PERMANENT FLOW.—The quantity of water which can be annually and in perpetuity drawn from an artesian well manifestly cannot exceed the quantity annually supplied to it. The quantity annually supplied depends on various factors, chiefly the extent of the high-lying outcrop, the rainfall on the area of the outcrop, and the capacity of the rock for absorption. Ordinarily the rock does not receive the whole of the rainfall, but permits a part of it to run off in surface streams, while another part escapes from the surface by evaporation.

The amount which can be drawn from a reservoir may depend, in addition, on the ability of the porous stratum to convey water. Where the stratum is thin or contains little interstitial space, the possible delivery of water is correspondingly small.

In the case of imperfect reservoirs the artesian possibilities are further limited by the natural escape of water at lower levels, and to this should be added the loss of water by slow transmission through the covering strata, for no rock is absolutely impervious to water.

From a perfect reservoir the water will rise in a well to the height of the outcropping edge of the stratum which receives the rainfall; from an imperfect reservoir it will not rise so high, and the amount of difference is related to the amount of water which escapes at lower levels, as well as to the resistance to flow encountered in different parts of the stratum. The height to which water will rise in a well depends on the pressure exerted by the water upon the cover of the reservoir, and that pressure is diminished by any draft upon the rerervoir. When an artesian well is opened and begins to flow, the pressure from the water of the reservoir is immediately diminished by the flow; in other words, the flowing pressure is less than the static pressure. If the discharge of a well be computed, by the aid of hydraulic formulæ, from the static pressure and the size of the bore, such computed discharge will always exceed the actual discharge, and the difference will usually be great. The difference is caused by the frictional resistance which the water experiences in moving through the porous stratum.

In this way the mutual interference of wells is occasioned. The boring of each well reduces the static pressure of the water of the reservoir all about it, the reduction diminishing outward in all directions. Any well bored within the range of this reduction meets with a relatively small water pressure and secures a relatively small flow. Reciprocally the boring of the second well diminishes the flow of the first.

If a series of neighboring wells be bored at the same level, the individual discharge of all the wells is progressively diminished, and the total discharge is at first progressively increased, but the limit of discharge for the locality is finally reached, and then the boring of additional wells gives no advantage. If two wells in the same vicinity head at different levels the one at the lower level discharges more water than the other, and the flow of the well or of a group of wells may be entirely destroyed by the sinking of new wells at a lower level. The same effect is produced by pumping water from wells, which is equivalent to a discharge at lower levels.

There is moreover, in the case of most wells, a certain amount of waste through the escape of water from the well to porous strata lying above the impervious cover of the reservoir. Such waste is apt to increase with time, and it manifestly increases with the multiplication of wells. It is therefore possible in most artesian districts to destroy absolutely the artesian head by the boring of numerous wells.

TEMPORARY FLOW.—Where the exposed outcrop of the artesian stratum covers a broad area and the rainfall is ample, it is usually the fact that the amount of water supplied to it is more than can be transmitted through its buried portion; but if the outcropping edge is narrow and lies in an arid region, it may happen that the stratum has capacity for the transmission of more water than is delivered to it. If these latter relations subsist in the case of a perfect or nearly perfect reservoir and that reservoir is tapped by numerous artesian wells, the initial discharge of water from the wells is greater than the permanent discharge. The wells in such case draw upon a body of water which may have required years for its accumulation, and their conditions of permanent flow are not reached until this accumulation has been exhausted. Thus in another and independent way the flow of artesian wells is liable to be diminished.

The following data, selected from the records of various artesian districts of the United States, illustrate chiefly the phenomena of interference, but they doubtless include also phenomena of temporary flow.

DENVER BASIN.—Artesian water was first obtained in the Denver basin in 1883. The flow yielded by the first well was so large and the water was of such superior quality for domestic use that other wells were put down with great rapidity. There are now in the city and its vicinity about three hundred wells. Many of the first wells had sufficient pressure to force the water into tanks in the tops of the highest buildings in the city, but as the number of wells was in-

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creased the pressure and flow of the older wells began to diminish, and finally, in the region where they are most closely grouped, they have failed to furnish water without the aid of pumps. Outside the region of closest grouping pressure and flow have been diminished, but not to so great extent. Deep wells are still bored at Denver, but not with the expectation of obtaining artesian flow.

DUBUQUE, IOWA.—The first well at this point for artesian purposes was headed nearly 200 feet above the level of the Mississippi river. Water was obtained in great volume and rose nearly to the surface. A few years later another well was put down at a lower level, approximately 100 feet above the river. A good flow was obtained, and this led to the boring of numerous wells. At first all were successful, but it was observed that with the multiplication of wells the flow from the older diminished, particularly when the new wells were headed at lower levels. Finally an exceedingly large bore was headed in the lower part of the city, but a few feet above the river level, and through this an unprecedented flow was developed; but within a few hours the flow from the other wells diminished, and within a few days all of those at the higher levels ceased to flow. Eventually the flow from the last-bored well dwindled to not more than twice or thrice that of the first well at the 100-foot level, and it is said to be still slowly diminishing.

CHICAGO.—The city of Chicago lies over an artesian reservoir, and it was hoped that it could be supplied therefrom with water for domestic purposes. But experimentation proved that while a few good wells could be secured a great number was impossible, and that the pumping necessary to derive a large supply of water would deprive the entire group of its artesian head.

ROCKFORD, ILL.—The municipality of Rockford obtains its water supply through five artesian wells which were bored in succession, and the supply was measured after the addition of each well.

Flow of Wells for Twenty-four Hours.

No. 1	1,000,000 gals.
Nos. 1 and 2	2,000,000 "
Nos. 1, 2 and 3	2,600,000 "
Nos. 1, 2, 3 and 4	3,000,000 "
Nos. 1, 2, 3, 4 and 5	3,500,000 "

The fifth well thus increased the supply only half as much as did the second. A private well was afterwards drilled at a distance of 1 mile and at a level 17 feet lower than the city wells, when the flow from the city wells immediately fell to 2,500,000 gallons.

WILLIAMS COUNTY, OHIO.—For the last thirty years it has been known that artesian water may be obtained from reservoirs in the drift in the northwestern portion of Ohio. In Bryan, the county seat of Williams county, an artesian well was bored in the public square, causing the village to be popularly called the "Fountain City." As the reservoir lay but a short distance beneath the surface, wells were easily produced and their number was rapidly increased; but it soon became apparent that their source could be overtaxed. The force of the flow was abated; the highest wells began to fail altogether; a pump was introduced into the public square fountain; and at the present time a sluggish flow is obtained only in the lowest portion of the village.

TOLEDO, OHIO.—The conditions are similar at Toledo. When the wells were first bored the water rose to a height of 14 feet above the level of Lake Erie, and this head was gradually lowered as the number of wells was increased. At the present time water is pumped from wells by the corporation and by private owners, and the head has fallen to 40 feet below the lake level.

OHIO VALLEY.—In the vicinity of Pomeroy, Ohio, and Mason City, W. Va., brine for the manufacture of salt has been obtained from artesian wells for the last thirty or forty years. When first tapped, the brine flowed freely, and it continued to do so for many years; but in 1865 the number of wells was greatly increased and the water head was thereby lost, so that pumping became necessary. Year by year the pumps have been lengthened, and now they are placed about 600 feet below the surface of the ground.

ALABAMA.—Although the lowlands skirting the Atlantic and Gulf slopes everywhere belong to what may be classed as an artesian district, artesian boring for supplies of water for domestic purposes was first inaugurated extensively in Alabama, and the history of interference is best known there. A representative locality is Finch's Ferry, where the bad quality of the surface water led the people to seek an artesian supply about fifty years ago. The first well obtained a strong flow of water from a depth of several hundred feet, and other wells followed. With the boring of each new well the flow from the older wells diminished, and the tendency became particularly noticeable when a well was bored at a lower level than any of the others on the banks of the Tuscaloosa river. In order not to destroy the older wells, it was found necessary to pipe the new well up to a height corresponding to the level at which the old wells were located. Even then the flow from the wells was so far diminished that some of them were unable to clear the casing of sand and debris, and so become clogged and ruined. At the present time but three wells continue to flow at the surface.

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IRRIGATION BY ARTESIAN WELLS IN VARIOUS COUNTRIES.

The cost of boring wells is so great and the quantity of water thus obtained is so limited that in most localities the special use given to the water must have high value in order to warrant the sinking of wells. Most frequently it is sought for domestic use. It is also sought for manufacturing and medicinal purposes, for the watering of stock, and for the production of salt. In some desert regions wells have been bored from point to point to furnish water for the use of travelers, and the water flowing from such wells is also used for the nourishment of gardens, but the irrigation is in this case an incidental result and not a primary purpose. Such gardens associated with travelers' wells are found in Abyssinia, Upper Egypt, and at various places on the Sahara, and also in Australia.

Artesian water has been successfully sought for the purpose of irrigation in China, Italy, Spain, the Sandwich islands, Algeria, California, and Utah. Details in regard to Chinese wells have not been ascertained. In California they are employed almost exclusively in the cultivation of fruits, and the same is true in Algeria. In Utah they are made to serve vegetable gardens. In Algeria about 4,000 acres have been reclaimed, and it is estimated that the present supply of water is competent to double this acreage. In California the wells are restricted to Los Angeles, San Bernardino, and San Diego counties, and it is stated by Mr. W. H. Hall, the state engineer, that less than 3,000 acres are irrigated. In Utah about 2,000 acres are irrigated. In each of the other countries named the extent of the irrigated land is very small.

The work in Algeria is peculiarly instructive, because agriculture was there initiated on the face of a desert, and because the institution of wells was scientifically planned. The following facts are selected from the extensive literature of the subject:

Irrigation in Algeria.—The initiative in the search for artesian waters in Algeria was taken by General Desvaux, of the French army, commanding at Batna, in the year 1855. At his request M. Ch. Laurent, a well known artesian expert, was sent to examine that portion of the Sahara desert lying within and adjacent to the confines of Algeria, with reference to the possibility of artesian waters and the best method of securing them.

The work of boring was under the immediate direction of M. Jus, C. E., assisted by Lieutenant Lehaut, of the army. The first well was sunk at Tamerna, in the oasis of Oued Rir'; begun early in May, 1856; completed June 19. Its flow was 4,010 litres (141 cubic feet, or 1,059 gallons) per minute; its depth, 60 metres (197 feet). From this date to 1860 fifty wells were sunk in the province of Constantine (Algeria), with a delivery of 36,000 litres (1,271 cubic feet, or 9,510 gallons) per minute.

Subsequent to 1860, records of wells are traced with difficulty, excepting for the oasis of Oued Rir', and it is probable that the information that follows is somewhat incomplete.

According to the best accounts at present available, the number of flowing wells now amounts to about 125, tubed with iron, and 500 native, tubed with wood; total, 625. Their yield is 240,000 litres (8,475 cubic feet, or 63,400 gallons) per minute. A well of 3,000 to 4,000 litres per minute (105 to 140 cubic feet) will irrigate from 100 to 200 acres, according to the nature of the soil. This gives a duty of from 42 to 84 acres per cubic foot per second, the former being nearer the average. With the present supply of water between 6,000 and 9,000 acres can be irrigated. At present not more than 4,000 acres are under cultivation, of which 3,706 are in the oasis of Oued Rir'.

It is stated that in the 30 years of well usage in this country the wells tubed with iron, with rare exceptions, due to defective tubing, have not varied in the amount of their delivery.

The following table is based on one by M. Rolland, printed in the report of the Societe Agricole et Industrielle de Batria et du sud Algerien, made in connection with the society's exhibit at the Paris Exposition of 1889:

Principal Groups of Artesian Wells.	Maximum depth of wells. *Feet.*	Number of wells.	Average flow per minute. *Gallons.*
Group of Ourir Ensura, Mraier, and Dendouga	269	12	640
Group of Sidi Khelil	318	4	280
Group of El Berd and Tinedla	321	3	560
Group of Zaouiet R'had and Mellaah	256	2	340
Great group of Mazer, Ourlana, Chria Saiah and Tala-em Mouidi, Ariana-Djama and Tiguedi-din, Couidiat Sidi Yahia and Sidi Amram	372	18	1,125
Group of Tamerna Khedina and Tamerna Djedida	252	10	750
Group of Moggar, Sidi Sliman, Bou Rekhis and El Kessour	292	9	750
Lateral Group of Sidi Rached, Bram, Ghamra and El Harihira	387	14	300
Great group of Megarin Khedima and Meggarin Djedida of Zaouia, Tebeshest and Tougourt, of Nezla and Coudiat el Koda	340	8	525
Terminal group of Temassin-Tamelath and Bledet Ahmar and El Gong	278	8	525

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DAKOTA SANDSTONE.—As already stated, this sandstone is the most important source of artesian water in the region of the Great Plains. It is believed that it has greater importance as a storehouse of water for irrigation than all of the other formations of the same region from which it is possible to derive supply by artesian wells. Its discussion and investigation must constitute the chief part of the discussion and investigation of the artesian problems of the Great Plains.

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Its water supply is received along the foot of the Rocky mountains, where it exhibits a nearly continuous outcrop. It is believed that there is a continuous discharge from its eastern margin, at least where that margin is not protected by heavy deposits of Upper Cretaceous clays. It therefore constitutes what has been styled an imperfect reservoir, but the conditions for artesian flow are more favorable in the Dakotas than in the states immediately south, and it is not improbable that they are again favorable in some parts of Texas. The above tables show that the wells of the James river valley exhibit higher pressure and a greater discharge than those of Nebraska and Kansas, where the eastern outcrop is uncovered, and further indication of the eastward movement of its water is found in the fact that the hydraulic head, as measured in the Dakotas, rises from east to west. The hydraulic head, or the height to which a column of water would rise under the static pressure, is 1,948 feet at Highmore, 1,876 feet at Miller, and 1,678 feet at Huron, reckoning in each case from sea level. From Highmore to Huron the distance is 62 miles, giving an average fall of 4⅓ feet per mile.

The sandstone reaches the surface at the west by an upward curve, and thus presents but a narrow belt of exposed surface. This belt is estimated to occupy an average width of about 800 feet for the region from Colorado to the northern boundary, and not enough is known of the border of the formation south of Colorado to form an estimate. The outcropping edge pursues a sinuous course and thereby increases the exposed area. Taking this into account, the feeding ground for the reservoir is estimated as the equivalent of a belt one third of a mile wide from the northern to the southern boundary of the United States. If the rainfall of this belt be taken at 15 inches, and one half of this be estimated as lost by running away from the surface and by evaporation, the remainder that goes into the sandstone, if it could all be brought up again by artesian wells, would cover a belt one fifth of a mile wide from boundary to boundary with 12 inches of water. This may be regarded as the outside limit of the permanent water supply derivable from the sandstone.

In order to estimate the land which may be irrigated, let us assume that but half of this supply escapes at the eastern edge of the formation; that the other half can all be brought to the surface through wells; that all the water flowing from the wells through the year can be stored without waste and applied to crops in the season of their growth, and that six inches of water will suffice to nourish the crops. We then have as the limiting area which can perpetually be served by the artesian water from the Dakota sandstone the equivalent of a belt one fifth of a mile wide and extending from boundary to boundary, or about 175,000 acres.

But the permanent supply is not all which can be drawn from the Dakota sandstone. There s an accumulated store of water competent to produce a temporary flow of importance. This is indicated by the phenomenal flow of some of the wells of the James river valley. The wells already sunk here and there over the valley furnish nearly half as much water as is annually received by the outcrop of the formation along the Rocky mountains west of the Dakotas, and there can be no question that the flow in this valley can be increased several times by boring additional wells at points properly distributed and selected. The yield of such wells in excess of the permanent supply must draw upon an exhaustible store, and must, therefore, be only temporary; but it may nevertheless prove sufficient to compensate for the outlay, at least if the number of wells bored be not excessive. The determination of the quantity of water thus temporarily available is a problem for the geologist and the engineer. The geologist can ascertain the extent, thickness and porosity of that portion of the Dakota sandstone which lies sufficiently above the level of the James river valley and is otherwise related to it so as to afford a reservoir delivering water under pressure; the engineer can carefully measure the static pressure and the volume of existing and new wells from time to time, and thus get the data for estimating the rate at which the supply is diminishing. When this has been done it will be possible to give intelligent advice as to the exploitation of the formation of that region for the purposes of irrigation.

The general character of the geologic data can be indicated by the information already at hand, but the result is necessarily very crude. At its outcrop along the foot of the Rocky mountains and above the circumference of the Black Hills the Dakota sandstone dips steeply beneath other rocks, and it is deemed probable that at all points it passes below the level of the James river valley within 3 miles of the outcrop. This gives as the maximum possible extent of efficient reservoir lying west of the Dakotas 1,200 square miles. Assuming the average thickness of the sandstone as 400 feet, and that the interstices filled with water constitute one tenth of its volume, we have stored a body of water equivalent to a lake 1,200 square miles in area and 40 feet deep. Such a maximum could only be attained if the reservoir was of the perfect type, and at

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that case the static pressure at Huron, in the James river valley, would be about 850 pounds to the square inch. As a matter of observation it is only 170 pounds to the square inch, and we are thus informed that the reservoir of water has a pressure far below the possible maximum. If, in view of this consideration, we reduce our estimate 75 per cent., we still have a most important body of water—a body competent to serve, with a layer 6 inches deep, 24,000 square miles of land for one year, or 1,000 square miles for twenty-four years. The assumption that the feeding ground for the artesian water to be raised in the Dakotas is limited by the same parallels of latitude which limit the Dakotas is arbitrary and crude. If the Dakota sandstone is a continuous formation, then a portion of the supply thus derived must be drawn off through Nebraska at the exposed edge in the eastern part of that state, where it is probable that the water finds free escape. On the other hand, it is possible that the Dakotas may draw from the sandstone water supplied to it beyond our northern boundary; while it is equally possible that a portion of the water absorbed along the outcrop of the formation in Montana flows northward rather than eastward, so as to contribute to the artesian supply of our Canadian neighbors.

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SUMMARY AND CONCLUSIONS.

It has been shown that the supply of water to be obtained through artesian wells is narrowly limited, the limitation arising from natural conditions of reception by reservoirs, transmission through them, and leakage from them, and being expressed practically through the interference of wells one with another. The permanent flow is in some cases much less than the initial flow.

Owing to the cost of well boring it is not economic to bore wells for the purpose of reclaiming land by artesian water unless the flow obtained exceeds a certain minimum. The economic limit is quickly reached in any district upon the multiplication of wells, and unless well systems are wisely planned there is great danger that the economic limit will be exceeded, and especially that new wells at lower levels will have the effect of destroying wells previously sunk at higher levels. Disappointment is also incurred when the temporary flow resulting from antecedent storage is mistaken for permanent flow. For these reasons exploitation with the drill should be guided by the results of surveys—geologic surveys to determine the stratigraphy and geologic structure, and engineering surveys to determine the limitation of discovered reservoirs. While the Dakota sandstone is one of the most important of the known artesian reservoirs, the amount of land which can be redeemed to agriculture through its aid is yet so small that disastrous results might follow if great expectations were aroused in regard to it. It is estimated that if all the water received by the Dakota sandstone could be brought to the surface by artesian wells it would cover to the depth of 1 foot an area of land equivalent, at the utmost, to a belt one-fifth of a mile wide and extending from the Canadian boundary to the Mexican.

This is the outside limit for permanent flow. The temporary flow may be large, but cannot be estimated from existing data. Such is the complexity of conditions, and so great is the danger of disaster through expensive exploitation in ignorance of the true conditions, that the subject demands the most skillful investigation which can be bestowed.

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I have laid before you somewhat fully this question of artesian wells, because the people from time to time in the United States have sought to obtain waters for irrigation on the Great Plains from this source. Many years ago Captain (afterwards General) Pope, of the army, attempted to discover artesian waters on the Staked Plains, and he commanded a military expedition to the country and bored for water, but he failed to find it. Some years ago appropriations were made by Congress to have artesian wells sunk in Colorado and Wyoming, and the work was continued for two years under the direction of the agricultural department. I believe that altogether $50,000 was expended, but no artesian waters were discovered. Still the people, now here, now there, from time to time, hope to obtain an artesian water supply sufficient for agriculture; and believing that this supply must always be inadequate, I have presented my views of the matter somewhat in full.

The above comprehensive statements of Major Powell should be looked upon as authentic as any information known to geologists regarding the water supply from the Dakota sandstone, unless it should be that he has neglected the two sources of water already mentioned other than precipitation upon the Dakota sandstone where exposed to the surface, viz., the water obtained here and there from the overlying Tertiary, and the underlying Triassic rocks of the north, and that obtained from rivers, such as the Missouri river at the Great Falls in Montana, and other streams. These extra sources of supply, which Major Powell apparently overlooked, would add quite perceptibly to the total Dakota water.

However, the citizens of Kansas may have no fears of the supply of water

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in the Dakota sandstone becoming exhausted unless it is drawn upon far more than it likely will be during the next few hundred years. The localities in our state where it can be obtained at depths within the reach of the ordinary farmer form so small a proportion of the whole area that wells may be relatively close together here and sufficient in number to draw largely from the localities under which the sandstone lies at so great depths it will rarely be reached. There is every reason, therefore, to encourage the drilling of wells wherever the cost is not too great for the purpose of obtaining Dakota water, either in the form of an artesian flow or from wells by pumping. Upon the estimate of Major Powell, just given, which is certainly none too large, Kansas can irrigate many thousand acres from the Dakota sandstone should she use only her allotted portion. But should she draw on adjacent territory by increasing the number of wells along the river valleys where the sandstone can be reached at lesser depths the amount of available water may be perceptibly increased. No one should hesitate searching for Dakota water on account of a fear that it would be insignificant in amount, at least not until many more wells have been drilled.

Character of the Dakota Water.

The character of the water obtained from the Dakota sandstone is variable. It seems to be entirely free from organic impurities. In this respect it is like most deep-seated water, for artesian waters generally have little if any organic matter in them.

Underground water is pure or mineralized according to its opportunities for dissolving soluble mineral salts. Could water be confined continuously in a perfectly pure mass of sand or sandstone, which had no soluble materials within it, and in which no soluble salts could be taken by infiltrating waters, its character would always remain pure. But nature has rarely accumulated masses of sand without having at least traces of soluble matter along with it. Few terranes are known anywhere in the world through which water can percolate for hundreds of miles without taking up mineral matter somewhere throughout the course. It is so with the Dakota sandstone, yet not universally so. For some reason which cannot be foretold, water obtained from the Dakota at one place is frequently very different in amount and character of impurities dissolved from that drawn from the same sandstone fifty or a hundred miles away.

The natural processes by which impurities are gathered from rocks by percolating water are such that it is usually exceedingly difficult to predict in advance whether water obtained at a given locality will be highly mineralized or not. After a sufficient number of wells have been made to admit a geographic study of the character of the water, then estimates of this kind may have some value. A sufficient number of such wells have already been made in Kansas to be of some help in this way. It is found that along the southern and southeastern limits of the Dakota the water is relatively free from impurities. The Santa Fe wells at Coolidge, for example, according to an analysis by Mr. W. D. Church, yielded but 24.36 grains of total solids to the gallon, or, expressed in parts of a million, the ordinary form of expression, it would be equal to 340.7. The wells at Syracuse, Santa Fe, and different ones in the southern part of Ford county likewise are remarkably free from mineral impurities. No analyses have been made of the water of any of these later wells, but one can judge from drinking that they are unusually free from mineral matters of all kinds, and particularly free from

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salt. Farther to the north and west the mineral material increases in quantity. The wells obtaining water from the Dakota in the vicinity of Ness City, however, have good water. But farther north in Russell and Norton counties, and west in Logan county, and elsewhere in the western part of the state, the water thus far obtained from the Dakota sandstone seems to be quite highly mineralized. Few analyses have been made from the Dakota waters from Kansas. Such as are available are given in the following table, to which is added a series of analyses of Dakota water from Colorado, copied from Mr. Gilbert.*

TABLE I.—*Kansas Water Analyses (results stated in ions).*

[Parts in 1,000,000.]

SUBSTANCE.	I. Burr Oak.	II. Conway.	III. Spring near Omio.	IV. Artesian well at Fay, Russell county.	V. †Coolidge artesian well.
Chlorine (Cl)	105.7	59.5	149.1	6,741.6	29.7
Sulphuric ion (SO_4)	2,940.7	1,654.7	5,064.0	2,066.4	.....
Carbonic ion (CO_3)	24.8	.....	.....	405.0	72.4
Potassium (K)	Trace.	19.2	282.6	39.2	.....
Sodium (Na)	31.7	38.6	186.2	4,921.2	19.3
Lithium (Li)	0.8	Trace.	5.3	.....	.....
Calcium (Ca)	462.3	521.4	475.3	171.4	31.4
Magnesium (Mg)	374.8	94.7	713.5	282.0	10.1
Iron (Fe)	14.4	Trace.	Trace.	.....	.....
Silica (SiO_2)	88.3	14.3	86.3	.....	1.8
Aluminum	62.2	5.5	102.1	.....	.....
Boric acid	Trace.	Trace.	3.9	.....	.....
Phosphoric acid	Trace.	.....	.....	.....	.....
Organic matter	.....	.....	.....	.....	0.4
Totals	4,105.7	2,407.9	7,068.3	14,626.8	.....

TABLE II.—*Kansas Water Analyses (results stated in salts).*

[Parts in 1,000,000.]

SUBSTANCE.	I. Burr Oak.	II. Conway.	III. Spring near Omio.	IV. Artesian well at Fay, Russell county.	V. Coolidge artesian well.
Potassium chloride (KCl)	.....	36.7	313.6	74.8	.....
Sodium chloride (NaCl)	80.6	69.4	.....	11,063.2	49.0
Sodium sulphate (Na_2SO_4)	.....	35.0	571.2	1,739.0	‡170.9
Magnesium sulphate ($MgSO_4$)	1,842.0	473.5	3,567.6	1,080.0	.....
Calcium sulphate ($CaSO_4$)	1,925.7	1,774.0	1,616.0	38.9	.....
Aluminum sulphate ($Al_2(SO_4)_3$)	.....	.....	650.5	.....	.....
Magnesium carbonate ($MgCo_3$)	5.3	.....	.....	231.0	35.5
Calcium carbonate ($CaCO_3$)	9.5	.....	.....	4.0	78.4
Silica	88.3	14.3	86.3	.....	1.8
Magnesium chloride ($MgCl_2$)	19.4	.....	.....	.....	.....
Alumina (Al_2O_3) and iron oxide (FeO)	.....	.....	.....	.....	4.7
Organic matter	.....	.....	.....	.....	.4
Totals	3,970.8	2,402.9	6,805.2	14,230.9	340.7

* Loc. cit., p. 38.

†Analysis quite incomplete.

‡Reported as "bicarbonate and sulphates of sodium and potassium."

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Explanation of Tables I and II.

I.—From Burr Oak, Jewell county; probably from the Niobrara, but no statement by analysts as to its source. Prof. G. H. Failyer and C. M. Breese, analysts.

II.—From Conway, McPherson county; probably from the Pleistocene sands. Prof. G. H. Failyer and C. M. Breese, analysts.

III.—Spring near Omio, Jewell county; probably from the Niobrara. Profs. G. H. Failye and J. T. Willard, analysts.

IV.—Artesian well of Mr. Kellogg at Fay, Russell county; from the Dakota sandstone. Prof. J. T. Willard, analyst.

V.—The Peck artesian well at Coolidge, now operated by the Atchison, Topeka & Santa Fe Rly. Company; from the Dakota sandstone. W. D. Church, analyst.

For comparison, the following analyses are copied from the report of Mr. Gilbert, *loc. cit.*, pp. 38–40:

TABLE III.—*Water Analyses (results stated in ions).*
[Parts in 1,000,000.]

SUBSTANCE.	I. Artesian well at Lamar.	II. Artesian well at La Junta.	III. Artesian well at Rocky Ford.	IV. Artesian well at Grand Hotel, Pueblo.
Chlorine (Cl)	33.3	54.0	28.2	277.2
Sulphuric ion (SO_4)	719.4	675.9	453.8	1,180.1
Carbonic ion (CO_3)	114.8	*a*169.6	*a*95.9	306.7
Nitric ion (NO_3)	.....	Not est.	.4	.....
Potassium (K)	.....	6.4	7.0	79.2
Sodium (Na)	355.3	360.0	259.2	201.7
Lithium (Li)	.....	Trace.	.5	18.3
Ammonium (NH_4)	.....	(*b*)	.8	.....
Calcium (Ca)	41.6	73.8	14.9	178.1
Strontium (Sr)	.....	(*b*)	.5	.....
Magnesium (Mg)	26.6	20.7	12.4	230.1
Iron (Fe)	.....	*c*.8	*d*2.8	34.2
Manganese (Mn)	.....	*c*.1	Trace.	.....
Silica (SiO_2)	49.6	*e*16.1	*f*11.9	Trace.
Alumina (Al_2O_3)	.....	Trace?	Trace?	.....
Totals	1,340.6	1,377.4	888.3	2,505.6

SUBSTANCE.	V. Carlile Spring.	VI. Iron Duke Spring, Canyon.	VII. Little Ute Spring, Canyon.	VIII. Underflow well at La Junta.
Chlorine (Cl)	117.1	833.0	1,187.8	56.1
Sulphuric ion (SO_4)	238.4	136.0	140.1	550.6
Carbonic ion (CO_3)	459.7	1,217.0	1,107.6	*a*100.0
Nitric ion (NO_3)	.....	.....	.....	Not est.
Potassium (K)	5.4	Trace.	Trace.	6.2
Sodium (Na)	253.8	1,154.4	1,385.7	143.2
Lithium (Li)	.....	Trace.	Trace.	Trace.
Ammonium (NH_4)	.....	.....	.....	.....
Calcium (Ca)	153.6	214.3	150.0	140.4
Strontium (Sr)	.....	.....	.....	(*e*)
Magnesium (Mg)	55.8	71.3	67.0	35.8
Iron (Fe)	2.5	Trace.	Trace.	.....
Manganese (Mn)	.....	.....	.....	.....
Silica (SiO_2)	.....	.....	.....	15.4
Alumina (Al_2O_3)	.....	.....	.....	.....
Totals	1,286.3	3,625.0	4,040.2	1,047.7

a Calculated from normal carbonates.
b Not tested for.
c In deposit.
d 2.6 in deposit.
e 2 in deposit.
f .3 in deposit.

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TABLE IV.—*Water Analyses (result stated in salts).*
[Parts in 1,000,000.]

SUBSTANCE.	I. Artesian well at Lamar.	II. Artesian well at La Junta.	III. Artesian well at Rocky Ford.	IV. Artesian well at Grand Hotel, Pueblo.
Lithium chloride (LiCl)	.....	Trace.	3	108
Potassium chloride (KCl)	.....	12	13	151
Sodium chloride (NaCl)	55	80	32	189
Sodium sulphate (Na_2SO_4)	1,030	1,000	671	393
Magnesium sulphate ($MgSO_4$)	29	.....	.....	1,143
Calcium sulphate ($CaSO_4$)	.....	.....	.....	.....
Sodium nitrate ($NaNO_3$)	.....	.....	0.5	.....
Sodium carbonate (Na_2CO_3)	.....	11	67	.....
Ammonium carb'n'te ($(NH_4)_2CO_3$)	.....	.....	2	.....
Magnesium carbonate ($MgCO_3$)	73	72	43	6
Strontium carbonate ($SrCO_3$)	.....	.....	1	.....
Calcium carbonate ($CaCO_3$)	104	184	37	444
Iron carbonate ($FeCO_3$)	.....	2	6	71
Manganese carbonate ($MnCO_3$)	.....	0.2	Trace.	.....
Silica (SiO_2)	50	16	12	.....
Totals	1,341	1,377	888	2,505
Sum of $MgSO_4$, $CaSO_4$, $MgCO_3$, and $CaCO_3$	206	256	80	1,593

SUBSTANCE.	V. Carlile Spring.	VI. Iron Duke Spring, Canyon.	VII. Little Ute Spring, Canyon.	VIII. Underflow well at La Junta.
Lithium chloride (LiCl)	.....	.....	.....	Trace.
Potassium chloride (KCl)	10	.....	.....	12
Sodium chloride (NaCl)	185	1,372	1,956	83
Sodium sulphate ($NaSO_4$)	353	201	207	341
Magnesium sulphate ($MgSO_4$)	.....	.....	.....	179
Calcium sulphate ($CaSO_4$)	.....	.....	.....	250
Sodium nitrate ($NaNO_3$)	.....	.....	.....	.....
Sodium carbonate (Na_2CO_3)	154	1,267	1,267	.....
Ammonium carb'n'te ($(NH_4)_2CO_3$)	.....	.....	.....	.....
Magnesium carbonate ($MgCO_3$)	195	250	235	.....
Strontium carbonate ($SrCO_3$)	.....	.....	.....	.....
Calcium carbonate ($CaCO_3$)	384	535	375	167
Iron carbonate ($FeCO_3$)	5	.....	.....	.....
Manganese carbonate ($MnCO_3$)	.....	.....	.....	.....
Silica (SiO_2)	.....	.....	.....	15
Totals	1,286	3,625	4,040	1,047
Sum of $MgSO_4$, $CaSO_4$, $MgCO_3$, and $CaCO_3$	579	785	610	596

Explanation of Tables III and IV.

I.—First artesian well drilled by the town of Lamar. Analysis by Dearborn Drug and Chemical Company, Chicago, Ill.

II.—First artesian well at La Junta; drilled by the Atchison, Topeka & Santa Fe Railroad Company. Sampled in September, 1895. Analysis by W. F. Hillebrand, United States Geological Survey. When examined by the chemist the water had deposited a slight brown sediment containing iron, magnanese, silica, and a trace of phosphoric oxide. This material is included in the analysis. Free and semicombined CO_2, 124.4. Total CO_2, 250.2.

III.—First artesian well at Rocky Ford; near Santa Fe railroad station. Sampled October, 1895. Analysis by W. F. Hillebrand, United States Geological Survey. Reaction faintly alkaline. Specific gravity at 30.5° C., 1.0008. When received by the chemist the water had de-

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posited a sediment containing silica, iron oxide, and traces of alumina (?) and phosphoric oxide. Free and semicombined CO_2, 106.6. Total CO_2, 176.9. Traces of bromides (?), iodides, and phosphates. Organic matter present, but not estimated. No boron, fluorine, or barium.

IV.—Trade name, "Colorado Lithia Water." This analysis, by A. Archie Cunningham, appears in a commercial circular, where it is stated in grains per gallon and in hypothetic combinations. It has been recomputed for this table. Trace of phosphates. No organic matter. Another commercial circular gives a somewhat different analysis, without name of analyst.

V.—Carlile spring, north bank Arkansas river, 18 miles west of Pueblo. Analysis by O. Loew, reported in Explorations West of the One Hundredth Meridian, volume 3, pages 621 and 622. Sample taken in July, 1874. Trace of organic matter. The spring deposits carbonates of lime and magnesia, building a mound.

VI and VII.—Iron Duke and Little Ute springs, near the state prison, Canyon. Analysis by O. Loew, from samples probably taken in 1874. Reported in Explorations West of the One Hundredth Meridian, volume 3, page 617. Water saturated with free carbonic acid. Traces of iron, potassium, and lithium.

VIII.—Surface well on the river bank at La Junta. Water drawn from the underflow of the Arkansas river. Analysis by W. F. Hillebrand, United States Geological Survey. Strong reaction for nitrates, but quantity not estimated.

Tables III and IV include not only analyses of the water of artesian wells at Lamar, La Junta, Rocky Ford, and Pueblo, but also of the water of a surface well from which the municipal supply of La Junta was pumped (1895), and the waters of three mineral springs which are probably derived from the Dakota sandstone. The Iron Duke and Little Ute springs, of Canyon, rise from the edge of the Dakota sandstone where it stands at a high angle in the "hogback" skirting the mountain base. The Carlile spring rises through Benton shales from an unseen source below, and is provisionally referred to the Dakota sandstone, because that is the first water-bearing rock beneath. The well at La Junta is sunk in the flood plain of the Arkansas river and is supplied by the river water, which undergoes no change except a filtration, eliminating the suspended sediment. It doubtless varies in quality with the volume of the river, being purest when the river is high. The sample was collected in September, 1895, with the river somewhat above mean stage.

Localities Where Dakota Water May Be Sought.

From the foregoing discussion it will be seen that water could probably be obtained from the Dakota sandstone almost anywhere over the state where the sandstone occurs, but that in character it would probably be undesirable if obtained from certain places. It has been stated that in the northwestern part of the state the Dakota lies at so great a depth it would be harder to reach than farther to the south. We are not in possession of sufficient data to warrant more than a general estimate of the depth at which the Dakota lies anywhere in the northwestern part of the state. This estimate would place it at not less than 1,000 feet below the surface north of the Union Pacific railway and west from Ellis county. We know nothing regarding the character of the water which might be obtained, neither of its pressure as regards artesian flow, etc. Geologists are in possession of less information regarding the underground conditions in the far northwest than for any other part of Kansas. Could a well be drilled to 1,000 or 1,500 feet in depth somewhere along the Rock Island railway from Colby west, or along the northern tier of counties, and an accurate record of the same be preserved, it would throw more light on the probable production of water from the Dakota sandstone over the northwestern eighth of the state than any other kind of an investigation which could be made for double the expense. For some unknown reason, as far as the writer has learned, not a single deep

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well has been drilled anywhere in the northwest part of the state, although many have been sunk elsewhere.

Those who are contemplating searching for water in the Dakota sandstone may find the accompanying maps helpful. On the geologic map of the state one can see the surface outcroppings of the Dakota. Anywhere to the northwest of this area the Dakota will be reached if the drill goes deep enough. In the southwestern part of the state the Dakota is covered by higher formations so that its southeastern limit cannot be seen. From well records it is known that this limit is approximately a line drawn from the southernmost Dakota exposure in Ford county to the southwestern corner of Seward county. If, therefore, we draw a line from the northeast corner of Republic county to the southwest corner of Seward county that portion of the state lying to the northwest is the portion throughout which one may reasonably hope to obtain water from the Dakota sandstone provided he goes deep enough. On the Underground water map, Plate XXII, the area is marked by a heavy line within which we have good reason for believing the water obtained from the Dakota will be sufficiently pure to be serviceable for domestic uses and for irrigation purposes. Throughout the greater part of this area one would rarely have to go more than 500 feet deep, but in Lane, Scott, Wichita, and Greeley counties one might have to drill deeper. It should be clearly understood that in outlining an area in this manner it is by no means intended to convey the idea that water could not likewise be obtained from the Dakota farther to the north. But as we are in ignorance regarding the water conditions in the northwest, as has already been explained quite fully, no predictions can be made regarding that part of the state excepting those of a most general character.

TERTIARY UNDERGROUND WATER.

The water of the Tertiary is that which is usually spoken of by citizens of the plains as "sheet water," or "underflow." The latter term seems to have been first employed by Judge J. W. Gregory,[1] of Garden City, Kas., in referring to what was supposed to be a mass of underground water everywhere present over the great plains of western Kansas flowing eastward. The term "sheet water" is now about as widely used as "underflow" and practically means the same thing, so that in common usage the two terms are synonymous. The latter term expresses within itself the popular idea of the great lateral extent of the water and says nothing about its movement, while the former expresses the popular notion of movement and says nothing of the lateral extent. The "underflow" or "sheet water" is therefore the water so often referred to in the preceding pages, and corresponds with similar masses of water found in all humid parts of the world wherever we have in combination the two conditions, a loose porous surface mantle of considerable thickness and a firm impervious floor beneath, provided of course the floor is not so greatly inclined that the water will flow away as fast as it accumulates. Such conditions are common along the wide valleys of all of our great streams, the the Mississippi river, the Missouri river, and rivers in other parts of the world, where all that is necessary to obtain water is to sink a well or a pipe from the surface to a proper depth below. There is therefore nothing mysterious about it, nothing unnatural or anything

[1] Garden City *Sentinel*, during spring of 1889, and numerous other newspaper and magazine articles.

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more than what anyone might expect who is familiar with all the geologic and climatic conditions of the great plains area east of the Rocky mountains.

How the Water Occurs.

In the Tertiary of Kansas it is usually found in a coarse sand or gravel, yet occasionally it is known to exist in a stratum of clay. Such an occurrence, of course, could not be with the clay entirely free from seams. Usually, it is most abundant in coarse sand or gravel. The position of the water-bearing beds is generally near the base of the Tertiary, but occasionally the water extends upward for 100 feet or more above the Cretaceous floor. Citizens of the plains are frequently speaking of the "first water," "secoud water," "third water," etc., expressing thereby an idea that the waters exist in two or more different horizons as separate and distinct beds. It is true that the water is frequently found at these varying depths, and that we may penetrate a water-bearing stratum at a depth say of 100 feet, below which an impervious layer of clay is reached that separates the first water found from a lower stratum of water-bearing sand or gravel, which in turn may likewise be separated by a bed of clay from a third water-bearing stratum. This is sometimes continued to four or five or more strata furnishing water, each of which is separated from its neighbor by a relatively impervious mass of clay. It is generally noted that when water is reached in a second or third water-bearing stratum it will rise to the level of where water was first found. This implies that there is a connection between the water at the various levels and that they should not be looked upon as distinct masses.

The explanation for this somewhat interesting series of phenomena probably is that the first water found marks the upper surface of saturation, and that were it not for the existence below this of impervious beds of clay, there would be a continuous body of water from the first water downward to the Cretaceous floor. The masses of clay are so irregular in distribution, as already explained, that frequently broad sheets or lenticular masses of it are found which are entirely barren of available water, and which consequently separate the body of water into two or three or more masses, the particular extent of which being dependent upon the arrangement of beds of clay.

This same irregularity of the clay deposits produces other unusual conditions that frequently deceive the inexperienced well driller. It is not an infrequent occurrence for two wells less than a mile apart to find a great variation of conditions. The first perhaps will find water at a depth of 50 feet, while the second may have to go 75, 100 or 150 feet before any water is obtained, the excess distance being passed through a bed of compact, plastic clay. It invariably results, however, that when the clay bed is finally passed, water is found in the sand or gravel beneath it which rises to about the level of the water in the first well. There is a great mass of clay lying north of Garden City, which is a good illustration of this. An irregular mass to the north of Ivanhoe is another good illustration of an area in which such conditions frequently are found. In the Little Cimarron valley numerous instances are known of such irregularities in depth at which water is reached. In fact there is scarcely a township in the Tertiary of the state which has not furnished one or more examples of this kind, so irregular are the masses of clay in position. But when such a mass of clay is finally passed the water always rises to the approximate level of water in neighboring wells where no clay bed was found. One may confidently expect this result to follow, unless the clay bed extends down to the Cretaceous or Red-Beds floor, which rarely occurs.

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The beds of gravel and coarse sand, which are good water-bearing materials, are equally irregular in distribution. Frequently they occur at the surface, being barren in such places of course. Elsewhere they occur only a few feet under the surface, and may have water within them. In other places they are at a medium or a great depth. They seem to depend upon some factor in their mode of deposition which has governed their position, about which we know but little at the present time.

Depth at Which Water is Found.

The depth at which water is found is exceedingly varied, and depends upon a number of conditions. It may always be assumed that the water rests on the impervious floor below the Tertiary, and that it extends upwards from this floor to whatever height the volume of water requires. The question of the depth to which one must drill before finding water is therefore largely a question of distance that must be passed before reaching the floor upon which the water rests. The surface of this floor is so irregular, as was explained in detail in preceding pages, that many ridges occur which are lifted above the level of the upper surface of the water. In such cases the floor will be reached without finding water. But elsewhere the nearness of the water to the surface is almost always dependent upon the nearness of the floor to the surface, rather than upon the geographic position at which a well may be located.

This is well illustrated by a comparison of the wells in the eastern and the western part of the Tertiary area. Along the Missouri Pacific railway near the Colorado line the Cretaceous floor comes near the surface. In some places wells have reached it without finding water, on account of striking one of the Cretaceous ridges. At other places the well driller has been more fortunate and has located his well over a place where water was available, which is hence sometimes reached at a distance not exceeding 40 feet. The elevation above sea level of this particular area is about 3,600 feet. Passing eastward from here the surface is inclined, and the surface of the Cretaceous floor is likewise inclined at almost the same angle. But in different places throughout Lane, Scott and Ness counties wells frequently go to a depth of 75 or 100 feet before water is found, simply because the loose Tertiary material has a greater depth above the Cretaceous floor. In Cheyenne county some of the tributaries of the Republican have cut channels almost to the Cretaceous floor. Wells dug in these valleys to a depth of from 10 to 20 feet find a great abundance of water, while wells on the high divide in Jewell county between the White Rock and the Republican are carried to more than 100 feet before water is obtained, although the surface in Jewell county is from 1,500 to 1,800 feet lower than it is in Cheyenne county.

There is a widespread notion throughout all the western part of Kansas that the underground water occupies a constant level. Scarcely a citizen can be found who is not confident that the water over the large areas is at an exact level corresponding to the level of the water surface in a great lake. This idea is confirmed by almost every well which is dug in any community. If it is started in a valley a much less distance has to be passed than though it is started on the uplands, so that in general the idea is correct; for such comparisons are rarely made over a distance of more than five or ten miles. This belief has resulted in great practical value to the citizens of the West, for it has enabled them to predict with tolerable certainty the depth to which

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a well would have to be carried in any particular locality before water would be found. The correctness of the idea in its local application is dependent upon the relative evenness of the Cretaceous floor surface. The irregularities in the floor already alluded to are but slight, rarely reaching more than 25 to 50 feet within a limit of five or ten miles. Therefore the proper way of looking upon the problem is to consider a mass of water above the Cretaceous floor having a certain thickness, and the loose sands or gravels or clays deposited upon the floor to irregular depths, so that where a ridge is produced by the Tertiary materials the depth to which one must go before striking water is correspondingly great.

It is believed that a great injury would be done to the whole of the western country were this popular notion destroyed, for it is of great practical value to every citizen who may wish to dig for water. But when we consider the area as a whole, over stretches of 100 miles or more, it is found that such an idea is erroneous, as the illustrations already given plainly show.

Other illustrations may be added of a like character, some of which, however, are more local in application. The water in the Arkansas river valley at Coolidge has an elevation of about 3,340 feet above sea level; the water in the same valley at Great Bend has an elevation of about 1,840 above sea level, making a difference of 1,500 in a distance of less than 200 miles. The water level at Liberal, near the south line of the state, is a little over 2,700 feet above sea level; while in the Crooked creek valley to the east, a distance of about 40 miles, it is 2,100 feet, having a fall of 15 feet to the mile, or 600 feet in 40 miles. The water level five miles to the south of Minneola, in Clark county, is about 2,500 feet above sea level; at Englewood, 20 miles to the south, it is about 1,900 feet above sea level, giving a fall of 600 feet in 20 miles, or an average of 30 feet to the mile. So it is in other localities. The actual inclination of the upper surface of the water level is dependent not upon the surface of the country in general, but upon the surface of the impervious floor upon which the water rests.

The accompanying map, Plate XXII, is a reconnaissance map shaded so as to show the depth below the surface at which water stands in the various wells. The areas over which it has to be pumped less than 75 feet are left bare; those over which the water has to be pumped a distance between 75 and 150 feet are lightly stippled; while the areas over which the water has to be pumped more than 150 feet are heavily stippled. An examination of the map will show that the particular geographic locality, whether on the east or west, has but little influence upon the depth at which water is found. The streams invariably have shallow water within their valleys, no one of them of any considerable importance being known in the western part of the state which does not have water at a depth of less than 75 feet. It will also be noted that the deepest water is on the high divides between the streams. Therefore, the north-and-south direction has an important bearing on the depth in most places, while the east-and-west direction has practically none.

It should be stated that this map makes no pretensions to absolute accuracy. Many difficulties have been met in its preparation. The area covered by the investigations during the last two seasons is so large that it has been impossible to gain information in sufficient detail to guarantee the exact accuracy of a map of this character. Another difficulty of equally great importance is the sparseness of settlements and the long distance between wells. No method is known for gathering such information, excepting by an investigation of the various wells as they now exist. In parts of the western counties one frequently may travel from 5 to 10 miles in certain directions without passing a house that is occupied.

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There is nothing at the surface over these boundless plains which gives even an inkling as to the depth below at which water is found, excepting the information gathered from neighboring wells. Still a third difficulty is the hindrance one meets in gaining information from the citizens. This is of little importance in the preparation of a map with the water contour intervals 75 feet, as this one has them, but it would be of great importance were a map in preparation to show the differences of depth for each 10 or 20 feet. It should be stated, to the credit of the citizens of Kansas, that in almost all instances inquiries made by myself or assistants were cheerfully responded to, and all possible assistance given. In a few instances, however, it was impossible to gain the desired information.

Eastward Movement of the Water.

The eastward inclination of the Cretaceous floor, corresponding in a general way with the inclination of the surface, results in an eastward movement of the water held in the Tertiary deposits. The velocity of the water movement will depend on a large number of conditions. Of course were it not for the resistance offered by the gravel and sand it would flow as rapidly as it does in the channels of rivers, and only a short time would be required to drain the whole western country. But the presence of sand and gravel in the water so retards its movements that it is possible to have an abundance of water found in a well within a mile, or even half a mile, of an outlet where the water is seeping into a river or creek channel. The velocity of the movement is therefore largely dependent upon the degree of coarseness of the gravel or sand. Water will flow through a mass of gravel, the pebbles of which will average three inches in diamater, with a decided current, provided the inclination of the surface is sufficiently great. But when the gravel is replaced by the finest of sand the surface inclination may be carried to 10 or 15 feet to the mile, and yet the movement would scarcely be perceptible.

The amount of water present in the sand also has an important bearing on the subject. If it is only enough to moisten the sand capillary action will tend to prevent movement. But if all the little inter-granular spaces are filled with water, so that we may look upon the sand as being suspended in the water, the current will become much more strongly marked.

Again, the character of the floor has a marked influence. The irregularities of the floor surface already described result in producing great variations in the actual inclination of the floor over different parts of the field. At one place near the eastern side of a valley trending north and south the floor will be inclined westward rather than eastward and will check the eastward velocity of the water. Again, we may have a basin with shallow walls, but covering a great extent. This basin will catch the water flowing into it from the west and will let it pass onward only when the basin is filled to overflowing. We may learn a lesson on this point from our surface water-courses. In them we usually have pools and rapids, or "riffles" as they are called. In the pool the water is deep and wide; on the riffle it is shallow and narrow. The velocity of water in the pool is scarcely perceptible, while on the riffle it is sufficiently great to produce the gurgling, rippling sound so well known to everyone. It is similar with the underground water of Kansas. In places it may have almost no perceptible movement; a broad underground body may exist wholly or partially surrounded by Cretaceous ridges from 5 to 100 feet high, or the walls may even have a greater height, as is known to be the case in some instances. But such lakes must have an outlet, either under the surface or above the surface, for the general eastward movement of the water will cause it to continue to accumulate until an outlet is pro-

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duced. The same irregularity of the Cretaceous floor which makes the existence of such underground lakes possible likewise produces barren areas, areas occupied by underground ridges or swells, which are lifted above the general level of the adjacent water.

We therefore have over the whole Tertiary area variable conditions and combinations of conditions which result in the accumulation of water in general all over the whole area, but in detail the water reservoirs are quite irregular. With an eastern inclination of 10 feet to the mile a basin would have to be very deep for its eastern walls to be higher than the general level of the Cretaceous floor only a short distance to the west. So, then, in a general way the water moves eastward through the valleys and over the ridges, moves slowly, being retarded by the resistance of the sand and gravel, apparently may flow uphill in passing up the western side of a cross ridge of the floor, but is ever impelled onward by the never-ceasing action of gravity which makes it flow eastward down the inclined plane, although the upper surface of the plane may be greatly corrugated.

With the great diversity of conditions regarding the coarseness of the sand and gravel, and with the varying conditions of valleys and troughs in the Cretaceous floor, it will readily be seen that we may have a great variation in the velocity of the water in its eastward movement, and consequently in the amounts of water which may be procured by wells in different locations. Could we combine a great depth of coarse gravel in a wide trough trending east and west, we would have the greatest conditions favorable to an excessive flow of water, or to the great strength and endurance of wells. But should a combination of fine sand and clay chance to occur, with the underground swells or ridges of the Cretaceous floor, the conditions would be most unfavorable for the production of water by digging. Such combinations of conditions as those just mentioned are practically known to exist in different localities of the state, while probably many other variations of combinations exist also.

Tertiary Springs.

It is a remarkable fact that almost universally over western Kansas the country abounds in never failing springs and pools of water. Such springs are sometimes high up on the side of a bluff, again low down in the bed of an arroyo, or river. These variable conditions, puzzling as they may seem at first, are readily understood, are in fact just what one would expect from the conditions above explained. If the channel of a modern stream has not been cut into the Tertiary deep enough to reach water level in the sand or gravel, as shown in figure 7, it will readily be seen that no water could pass outwards into the cut from the general underground water. But if the stream has cut its channel to a depth below the water level, as shown in figure 2, no matter whether it has reached the Cretaceous floor or not, there will be a seepage along the banks from the underground water. If the porosity of the material should be uniform the seepage will be uniform and the springs scarcely noticeable. But such conditions are hard to find. A bed of clay, a mass of coarser or finer sand, or some other irregularity intensifies the seepage at one place at the expense of another, and a spring is the result. Farther down the stream where the channel has been cut far down into the Cretaceous floor, as shown in figure 9, leaving the base of the water level 100 feet or more up the hillside, the springs will be found at a corresponding altitude. A stream fulfilling the conditions of figure 7 will have no water in it except from the surface water drainage, while the one corresponding to the conditions shown in figure 8 usually has an abundance of water along its

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course throughout the entire year. Still farther below, as shown in figure 9, with the source of the water supply far up on the hillside, it often happens that the stream has accumulated a mass of sand and gravel along its newly formed channel which absorbs and conceals from view the water flowing into it from the springs above. It is a most common observation along many of the Kansas streams to find that at certain places springs and pools of water abound equaling in quantity and quality those commonly found in more humid regions, while both up stream and down during the long summer months the whole valley seems to be as dry and destitute of water as a desert.

It sometimes happens that a shallow trough in the Cretaceous floor trends east and west. In such instances springs rarely occur along the side of the trough, but at the lower end they are very abundant. Of course it will not matter how high the Tertiary material is piled above the floor of the trough, as this has no bearing on the water question. A good example of this is the long Tertiary ridge between White Rock creek on the south and the Republican river on the north. Here is a high Tertiary ridge extending all the way along the north side of Jewell county, under which the Tertiary water is found in the greatest quantity. At the eastern extremity of the ridge, where it passes down into the Republican river, springs of good, cold, pure water are very abundant, and very strong. The cross-section, figure 10, and the Tertiary, as shown on the geologic map, Plate XXIII, in connection with the hydrographic map, Plate XXII, tell the whole story.

In one other case, that shown in figure 11, no spring water can be found. Here a stream cuts into the Cretacious floor at a place where it slants from the stream, and of course the water drainage would be away from the stream. This represents the conditions at the state well, No. 1, Hamilton county, six miles north of Kendall.

Under the discussion of the Meade artesian valley later in this Report, additional springs are discussed.

Areal Extent of Tertiary Water.

The area under which the Tertiary waters of Kansas exist in sufficient quanties to be of importance in irrigation or extensive stock raising are best represented by the accompanying maps—one the geologic and one the hydrographic. It includes all of the Tertiary area of the state west of the 98th meridian, excepting narrow fringes along the borders where the thickness of the Tertiary deposits is not sufficient to hold the water. In addition to these areas it is known that the larger river valleys have ground water of great importance. The Kansas river from Salina to Kansas City is such a stream. With a valley averaging four miles wide and a length of 150 miles we have an area approximating 600 square miles, or more than 350,000 acres beneath which is water sufficient, if lifted to the surface and properly applied, to irrigate the whole of the valley to as great an extent as there is any probability of time ever demanding. Similarly other rivers in eastern Kansas furnish the same conditions, but to a less extent.

Another class of rivers, however, rivers in the Tertiary area itself, need special notice. An examination of the map will show that along the Solomon and the Walnut, and possibly other streams, is a narrow belt of ground water, while on either side of it is a correspondingly narrow belt without water, and still farther away from the streams on the high uplands the Tertiary area again appears. This represents the exact condition as observed in numerous instances, nowhere better illustrated perhaps than the Arkansas river valley from Hartland to the western side of the state. In such cases the Tertiary floor has been reached and

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penetrated in the erosive process of the river until a deep gorge or canyon has been cut far below the base of the Tertiary deposits. Subsequently, due to the decrease in the corrasive action of the river, the valley has been filled with sand and soil from the adjacent hillsides and from the areas farther to the west. In this way we have produced conditions identical with those of the general Tertiary area, a heavy mass of loose pevious material which will allow water to percolate freely through it, resting upon an impervious floor, and walled in on all sides by the impervious walls, so that the only outlet is downwards in the direction of the flow of the stream. Therefore, in the river valley in such instances, we have a genuine underflow, often existing in large quantities, and generally sufficiently near the surface to be of great value. But upon ascending the bluffs on either side, the conditions change and the underflow disappears. By passing outwards from the stream in most cases the Tertiary area is reached on the high uplands along the divides. Here again another and usually an entirely separated body of ground water is reached.

Three good illustrations of such conditions are the Solomon river, in the vicinity of Stockton, the Walnut river, in the vicinity of Ness City, and the Arkansas river from Hartland to Coolidge. Along the valley of the Solomon large quantities of water exist. It is true that here and there a well, even in the valley at Stockton, fails to produce water. But this is because an underground ridge of the Cretaceous floor reaches downward into the valley, and has sufficient height to be above the level of the underflow. On the adjacent bluffs, however, and for some distance back in both directions the surface is covered with the Niobrara chalk and a thin mantle of soil. No water of any considerable importance has ever yet been found in those chalk beds, so that on each side of the river valley is an area, a narrow strip, almost totally void of water. Still farther away from the river, as is shown on the map, an eastern projection of the Tertiary exists, producing high uplands, broad and flat, beneath which, at a distance of from 40 to 60 feet, large quantities of the Tertiary water can be found.

Along the Walnut river, in Ness county, the wide valley is filled with Tertiary materials, beneath which there seems to be great quantities of water. In this valley the water is continuous eastward throughout its entire length. As the Tertiary is passed other accumulations of loose material occur, so that the proper conditions obtain throughout the entire distance for the accumulation and maintenance of a strong body of water. In passing laterally either north or south from Ness City, we come upon the Cretaceous formations. Southward there is but little Tertiary within many miles, and a corresponding lack of water, excepting as it is drawn from the Dakota sandstone over 200 feet below. Northward the high bluffs are composed of the Niobrara chalk, on top of which is a mantle of Tertiary which soon reaches sufficient thickness to become a great water-bearing formation. As a result there is a belt of Tertiary material between the Walnut and the Smoky Hill rivers throughout the whole width of Ness county, and even beyond, which has large quantities of water within easy reach of the surface.

Along the northern side of the Arkansas river westward from Hartland we have a repetition of similar conditions. In the valley itself the quantity of water is so great it has never been measured. The bluffs are of the Benton limestone and shales, but beyond them to the north the Tertiary appears, and back from the river four or five miles it has reached a thickness sufficiently great to become a water-bearing horizon. The state well north of Kendall, five miles from the river, found water at 170 feet, while the Cretaceous floor was not reached until nearly 200 feet had been passed, leaving a thickness of about 25 feet of good

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water-bearing sand, which produced water to as great an extent as has yet been tested.

Other rivers in the Tertiary area exist under quite different conditions. Of these the Smoky Hill is the best example in the state. For some reason, as yet unknown, this stream has not succeeded in accumulating any considerable amount of pervious material in its valley, where it has been cut down into the Cretaceous. In other words, the filling-in process has not yet been reached by the river. As a result, nowhere along its course, throughout the Tertiary area, do we find much water in the valley, at least it is not sufficiently extensive to be of much importance in irrigation. It is true, in places where the detritus has reached a thickness of 6 or more feet, a considerable amount of water can be obtained by digging, but compared with the water of other areas this is of little importance. But when we ascend the bluffs and pass outwards to the broad plains of the great Tertiary areas water in great abundance is found. We have the anomalous condition, therefore, of wells in the river valley being barren, while wells on the high uplands a mile or more away, and often from 200 to 300 feet above the river, are very productive. Figure 3 will help to make this clear.

Tertiary Artesian Wells.

Artesian water is found in the Tertiary or Pleistocene formations of Meade county. During the summer of 1896 the writer studied the artesian area in connection with investigations made for the Hydrographic Bureau of the United States Geological survey under Mr. F. H. Newell, Chief Hydrographer. A report on the same was made to Mr. Newell, which at this date, January 1, 1897, is still in manuscript form. Through the courtesy of Mr. Newell the portion referring to the Tertiary artesian water is here copied.

Artesian Wells of Meade County.

GEOGRAPHY.

The Meade artesian area is located in the valley of Crooked creek, to the northeast of Meade Center, extending from Meade Center to Wilburn. This gives it a length of about twenty miles, with a width in places of nearly six miles. The area over which artesian water has been found to a greater or less extent covers from sixty to eighty square miles. It is a broad, flat valley, apparently almost level, with almost no irregularities of surface within it, excepting here and there small drainage channels which are cut downward from five to eight feet, almost like an artificial ditch. On all sides and in every direction from the valley the ground is higher, so that there appears to be a natural wall all around it. On the east and southeast the wall is from 50 to 100 feet high, with gently sloping sides, and the surface is largely covered with sand-hills. On the north there is a gentle rise towards Crooked creek, producing a maximum elevation of about 75 feet between the main part of the valley and Crooked creek itself. But at the northeast, towards Wilburn, the wall is much more abrupt, rising rapidly to a height from 100 to 140 feet. A few drainage channels originate in the high grounds to the west, and pass across the artesian valley to Crooked creek. Such channels present the appearance of mere ditches throughout their whole length within the valley, usually having their banks lifted higher than the ground some distance back, showing the filling-in process to have been carried on by them as is so commonly done by rivers after reaching their base-level. Crooked creek is throughout the valley scarcely distinguishable from some of its tributaries just described. It is almost insignificant in appearance, generally but a few feet wide, and can rarely be observed in the landscape until one is within a hundred feet of it, so closely does it resemble an artificial ditch in its general characters. It has also lifted its banks higher than the adjacent land to so great an extent that in some instances the surface a quarter of a mile away is lower than the top of the bank immediately at the creek.

The uplands to the west of the artesian valley increase in height rapidly so that the plains to the north and northwest of Jasper, as shown by the Meade topographic sheet, are more than 2,700 feet high not more than 10 miles away, while the general elevation of the artesian valley is between 2,400 and 2,500 feet. The Tertiary ground water of the high plains to the west is found at a depth of from 125 to 150 feet, consequently the level of the water ten miles to the west of the artesian valley is from 100 to 120 feet above the surface of the valley itself.

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GEOLOGY.

The artesian valley throughout is covered with Tertiary or Pleistocene. The thickness of these formations is not known. The different artesian wells vary from 50 to 250 feet in depth, no one of which has yet passed through them. To the north, beyond Crooked creek, the Benton is shown at the surface in a few places and has been reached in many of the wells. To the northeast, a few miles beyond Wilburn, the Dakota was found by different wells. South of the valley the Red-Beds appear at the surface, as the Benton and Dakota gradually grow thinner at the south until they disappear. It is further believed that the strata were here faulted so that the Meade valley was sunk to an unknown distance, but at least 200 feet, and that it has since been filled in to a considerable extent, probably in Pleistocene time. The character of the materials as shown in the borings from different wells here and there over the valley cannot be distinguished from the Tertiary materials adjacent on all sides. It is composed of silt, and clay, and sand, and fine gravel quite irregularly mixed, so that there is no greater continuity of the bedding plains than may be found in the Tertiary deposits elsewhere.

The mortar beds produced by the cementing of the coarse sand seem to be almost wanting, but here and there the finer sand and clay are frequently partially cemented by calcium carbonate producing a certain degree of hardening similiar to that observed in the mortar beds elsewhere. But in character the cement so frequently assumes a concretionary aspect that it seems probable it was deposited in the sands and clays by infiltrating water after they were placed where they are now found.

The artesian water, therefore, is drawn from the Tertiary, or Pleistocene beds composed of materials in every respect similiar to the Tertiary materials surrounding the valley upon all sides. It seems sharply distinguishable from the Dakota artesian water known to exist to the north and northwest.

WATER NOT ARTESIAN.

The whole of the artesian valley is supplied with the ordinary underground water, which may be found at from 5 to 15 feet below the surface. Its abundance is not known, as no one cares to use it. It would seem that it is sharply distinguished from the deeper-lying artesian water, as it has no apparent artesian properties. But at the same time it must be admitted we are in relative ignorance regarding the reasons why the two are not connected.

THE ARTESIAN WELLS.

The artesian wells at present in successful operation number considerably more than 300, an exact enumeration of them not having yet been made.[1]

In depth the wells vary greatly, some of them being but little more than 50 feet deep, while others are as much as 250 feet. There is a strong similarity between the materials passed through by all the wells if considered in a general way, but a lack of similarity if considered in great detail. Each one passes through the surface soil, below which it encounters alternations of clay, sand, and soil. The sand is frequently partly cemented so that the well drillers speak of it as rock, but the layers thus cemented are rarely more than 12 inches thick, and frequently not more than 6 inches. Two wells within 40 rods of each other found a great variation in the number and relative position of the beds of clay and sand and rock, but all of them pass through the same materials. As far as could be learned there is no particular stratum which must be reached before artesian water is obtained. A mass of bluish clay, the color showing that considerable unoxidized organic matter is contained within it, frequently rests on the top of a bed of uncemented sand stained yellow with iron rust. Such sand always contains water, and generally the artesian water, and indicates by the degree to which the iron oxide is produced that the artesian water is a surface water which has not yet been robbed of its supply of oxygen gathered from the atmosphere.

But few wells have been studied carefully while being drilled. In August, 1896, the writer had a well put down specially for making an examination. It was located on the land of Mr. W. F. Foster, near the center of section 6, township 31 south, range 27 west. The drill used was one rented from Mr. Cooper, a well driller living in the valley. In addition to the bit on the end, a pump was attached so that water was forced down through the drill pipe, causing a constant flow upwards outside of the pipe, the current bringing up the cuttings of the drill. In this way it was impossible to tell within a few inches, or possibly a foot or two, of the depth at which a change of material was made unless there was a change in the degree of hardness of the material, passing from a hard to a soft or a soft to a hard layer, so that the one turning the drill could detect the difference. The well was carried to a depth of 167 feet and obtained a moderate flow of water from a loose, yellow sand. The record of the well follow

[1] A more detailed investigation of this valley is contemplated for the future.

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No. of stratum.	Thickness of stratum, feet.	Well of W. F. Foster, On section 6, township 31 south, range 27 west. Description of stratum.	Total depth to bottom of stratum, feet.
1.....	7	Soil and subsoil.....	7
2.....	13	Mortar beds (almost entirely free from sand or gravel, small concretionary mass of calcium carbonate intermingled with the clay).....	20
3.....	11	Light-colored clay, grading into gray and grayish-blue in color..	31
4.....	5	Blue clay which grades into No. 5.....	36
5.....	4	Light-colored clay which grades into No. 6.....	40
6.....	10	Blue clay.....	50
7.....	2	Mortar beds similar to No. 2.....	52
8.....	14	Blue clay.....	66
9.....	19	At depth of 66 feet began striking thin layers of hard substance, which seemed to be layers of sand sufficiently cemented with calcium carbonate to produce considerable resistance to the drill. Three or four of these were passed during 19 feet. They were separated from each other by beds of blue clay.....	85
10.....	3	A fine white sand at the top, grading into bluish sand at the bottom, and which was sufficiently cemented with calcium carbonate to produce a relatively solid rock.....	88
11.....	3	Blue clay, at the bottom of which was a hard sandrock similar to those above.....	91
12.....	11	Clay, with sand intermingled.....	102
13.....	3	Light-colored sand.....	105
14.....	1	Soft clay, grading into No. 15.....	106
15.....	6	Alternating layers of clay and sand sufficiently cemented to be noticeable.....	112
16.....	18	At 113 feet struck unusually (for this well) hard sandrock less than 1 foot thick, below which there was a frequent alternation of clay and sand partially cemented, the layers being from 2 inches to 6 inches thick.....	130
17.....	20	At about 130 feet a fine sand with clay was struck, a light bluish-yellow in color, which was 20 feet thick.....	150
18.....	10	At 150 feet the color changed to more of a reddish-brown.....	160
19.....	7	At 160 feet the sand became coarser and the clay redder in color. The drill gradually sank of its own weight, occupying less than two minutes in sinking 3 feet, while the pump was kept running. At the bottom of this formation the clay seemed to disappear almost entirely, and the artesian flow came from the coarse yellowish sand.....	167

It was learned from Mr. Foster and the parties who did the drilling that a well previously drilled, located not over forty rods to the west, struck almost none of the harder material. The house well of Mr. Mars, a quarter of a mile to the east, one of the best wells in the valley, likewise struck none of the harder materials. Each of these two wells was drilled in about four hours' time, which further shows the soft character of the materials passed through.

It was reported that a few wells not more than 50 feet deep have produced considerable amounts of artesian water. From this they increase in depth to a maximum of 250 feet, a well drilled on Mr. Cooper's place about two and a half miles to the southwest of the Foster well.

With but one exception no well has yet been drilled in this valley large enough to admit more than a three-inch pipe. The drills that have thus far been available for use have been owned locally, and have been handled by men who have had but little experience in well drilling outside the valley. Usually a gas-pipe from 12 to 18 feet long is put down to shut off the first water, after which no piping is used. In a few instances wells have been piped almost their entire depth. The best wells now flowing gave but little water when first drilled. They had a mild flow bringing up sand, the flow increasing as more sand was brought out. In some cases two or three wagon-loads of sand have thus been thrown out by the water, after which time the flow reached a maximum amount, and the movement of sand almost ceased. Little experimenting has been done to determine whether or not an increase of water could be produced by properly piping the wells, or by pumping them vigorously until all the loose sand was removed. It is quite possible that flows could be greatly increased by these methods.

An artesian flow may be found almost anywhere over the valley. Yet there are many instances in which wells have been drilled that did not yield a sufficient quantity of water to be of value. It is difficult to decide, with the data at hand, why some of the wells are successes and some are failures. In a few places the surface elevation seems to be a little too high. A well in the bottom of a ravine yields a pretty good flow, while one drilled on the banks near by will have the water raise almost to the surface, but not high enough to flow. In other instances two or more wells may be close together with the surface elevation the same, some of which will be good flowing wells and others not. It seems probable that this difference is due to two or

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more causes. The great diversity in the character of the material passed through in drilling the different wells makes it certain that the clay beds are irregular in formation and distribution. One can well understand how the disposition of these beds may cause a variation in the results obtained. A mass of clay may carry the water so deep that the drill did not reach it. Or it is possible for a mass of sand to be entirely surrounded by an impervious clay so that a drill penetrating the sand will receive no flow because there is no pressure on the water the sand contains. The heterogeneous character, therefore, of the clay beds may be one of the main causes for such differences in wells so close together. The experience with wells which are of little value for weeks, or even months, after which time they become strong flowing wells, shows that in some way they become choked with sand, permitting only a mild flow until the sand was removed by pumping or otherwise, after which a much stronger flow was obtained.

It seems that the northern and western side of the valley is the more productive. At present the best wells are in the northwestern portion of the valley. But flowing wells have been obtained all the way from Wilburn on the northeast to Meade, or possibly a mile or two south of Meade, to the southwest. The flow of the wells varies from a pailful in five minutes to 45 gallons per minute. As a more detailed study of the area is contemplated for next season it was decided to postpone for the present the gathering of exact data regarding the wells. However, approximate measurements were made of 20 or more of the strongest wells. A large bucket was accurately measured and filled by the flow a number of times, one party handling the bucket, the other holding a watch, to determine the number of seconds required for filling the bucket. The test was repeated a large number of times to eliminate errors of observation as far as possible. In this way it is believed the probable error of measurement is not greater than 1 or 2 per cent. Five or six different wells were found to yield 45 gallons per minute. Twenty or 30 wells exist which yield 30 gallons per minute or more, from which the wells grade downwards to the minimum flow. It may be roughly estimated that the actual flow of the wells during the summer of 1896 was equivalent to a hundred 30-gallon wells. This would give a yield of water of about 400 second-feet.

The water obtained from the wells is largely used for irrigation purposes. Yet it must be confessed that many of the wells were simply left flowing, and the water allowed to go to waste without any attempt to use it. The number of acres irrigated were much fewer than the estimated possibility.

SOURCE OF THE ARTESIAN WATER.

From data already given regarding elevations in the artesian valley and the uplands to the west, it will be seen that the water level from five to fifteen miles to the west of the valley is considerably higher than the surface of the ground within the valley. The wells along the arroyas to the west of the artesian valley have artesian properties which gradually decrease westward. The depth of the water on the uplands to the west is nearly as great a mile away as it is five, excepting where the well is located in an arroya of greater or less depth. It will not do, therefore, to consider the water on the uplands to the west as moving eastward under favorable conditions for creating a pressure throughout the whole distance, but rather it should be considered that the impervious Cretaceous or Red-Beds floor slopes to the east at nearly the same rate as the surface, and that the water is gradually moving down this gentle incline toward the east. Here and there, however, it passes under local clay beds, which prevent the water from rising as high as it otherwise would, and a corresponding pressure is set up. In some way, as the large artesian area is approached, the water descends and in the descent passes underneath the clay beds of the valley, so that a limited pressure is established. Only a few experiments were made to test the height to which water would rise in an open tube at the well. All such experiments show that the rise is only a few feet in height, perhaps always less than 20. The pressure which causes the flow from the wells, therefore, cannot be due to the extra height the water has ten miles to the west, otherwise the head would be much greater and the flow correspondingly stronger. It would seem rather that the pressure is due to the head generated by the gentle dipping downward of the water level as it passes under the clay beds near the west border of the artesian area, perhaps rarely extending farther than from two to four miles away. The water in the artesian wells seems to be continuous with the general upland water to the west. It is like it in character, and the two areas are connected by various wells, so that there can be little doubt on the subject

SPRINGS IN THE ARTESIAN VALLEY.

Springs throughout the artesian valley are by no means unknown. A few are located in arroyos along the western border. These occur here and there over the valley, some of which are of considerable note. The most noted area for springs is in the vicinity of Mr. Simms's ranch, a mile and a half north of Fowler. On the eastern side of Crooked creek, a fourth of a mile or more away, a large area is so supplied with springs and seeps that hundreds of acres of land are rendered worthless. The springs are principally located just along the border line between the valley proper and the higher lands to the east. The rank growth of vegetation produced by the

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moisture has provided a tough and heavy sod which protects the softer ground beneath, so that the range animals can pass over it with safety, excepting in the immediate vicinity of the strongest pools. Here the upward movement of the water is so rapid, and the sand which is frequently brought up with the water accumulates to such an extent that vegetation does not grow for a few feet round the spring. Such areas are death-traps to range animals. Mr. Simms stated that numerous instances have come under his observation of animals becoming engulfed in the mud and sinking out of sight, or if not out of sight entirely, sinking the full length of the body. In many of the springs, by using a long pole, one can feel bones at a distance of from 8 to 15 feet below the surface, presumably the bones of buffalo and other wild animals which lost their life in the springs.

It seems probable that these springs and the artesian wells receive their supplies from the same source. The character of the water is the same; the location in general is the same; for artesians wells can be obtained in the immediate vicinity of the springs, and the whole character the surroundings implies that there is no essential difference between the sources of the two classes of water. The location of the largest springs is near the southeast valley line, along the eastern side of the valley. If the valley has been dropped by faulting, the water-bearing sands in the valley are doubtless on a level with the Red-Beds or the underlying Dakota on the east. This condition would cause springs to be more abundant along the east line than elsewhere.

Farther south along the western tributaries to Crooked creek, and in the valley of Crooked creek itself, numerous springs and seeps abound. The largest amount of spring water flows through Spring creek—a stream about three miles south of Meade. Springs are abundant throughout almost the entire length of this stream, but are particularly so about three miles south of Meade, in section 21. Here most beautiful springs exist. At one place with an area of not exceeding 10 square rods, the cold, clear water comes bursting forth from under the mortar beds bluffs, forming a stream like a mill-race. An approximate measurement from this one area gave fully three second-feet, which is equivalent to more than 2,000 acre-feet, or enough to irrigate more than 2,000 acres with 12 inches of water each year. This is the most remarkable group of springs anywhere throughout the West. It would seem that there is an abundance of water, however, in this one little stream to irrigate more than 3,000 acres 12 inches each year, provided it was all used for irrigation purposes, and proper care taken to guard against waste. About a mile below this group of springs a ditch draws water from Spring creek to irrigate the alfalfa fields on Crooked L ranch. The remainder of the water passes on down the creek, and is principally used for stock water, although here and there small amounts are taken for irrigation. South from Spring creek, the next most important tributary from the west is Stump arroyo, a stream along which frequent springs occur, but which does not yield nearly as much water. One principal ditch draws water from this arroyo to the farms below.

All these springs are in the true sense connected with the artesian area to the north, and the discussion of them is relevant because they throw light on the origin of the water in the artesian valley.

Reviewing the whole matter regarding the origin of the water in the artesian wells and artesian springs, it must be admitted that it seems the water is continuous with the ordinary underground water to the west, and that it is therefore a part of the same. It is certainly distinct from the Dakota water, and is so deep that we cannot think it lies above the eastern extension of the water plain on the west.

QUANTITY OF AVAILABLE WATER IN THE ARTESIAN VALLEY.

It is of great practical importance to arrive at some conclusions regarding the amount of available water in the artesian valley, and to decide whether or not the continued use year after year is liable to destroy the supply. It will hardly do to assume that the wells could be put down every few rods over the entire valley, each one of which would flow independently of the others. Artesian water in almost all places thus far observed in any part of the world has been found in wells which acted sympathetically with each other. Should a strong-flowing well be closed ordinarily adjacent wells have their flow accelerated. But few experiments have been thus far made in the Meade artesian valley to determine the influence of one well over another. Many inquiries were made of citizens here and there in the valley, and conflicting statements were given on the subject. Some individuals were positive that the rapid flow of one well sensibly diminished the flow in weaker ones near by, while other farmers as stoutly stated that on their farm the flow of one had no influence on the flow of another. It is probable the former class of reports are correct, in fact it would be quite remarkable were they not.

This condition need not necessarily argue against the large supply of water in the valley. In all cases where wells are close together, they mutually influence each other, provided the rate of flow through the water-bearing strata, sand, gravel, or whatever it may be, is not sufficiently great to maintain the flow as long as the supply lasts. But most beds of sand and gravel are so close-grained that there is an appreciable check in the rate of movement of the water in the sand, which in most instances will result in sympathetic action of adjacent wells.

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It appears to the writer, therefore, that the question of supply of water for artesian wells depends more on the source of the water than it does on the mere rapidity of the flow from any well, or from a group of wells. The facts already given certainly imply, as has been seen, that the source is the ordinary underground water to the west and northwest. If this is correct, the question of supply is essentially the same as the question of the supply in the upland areas. As long as the water exists on the uplands from five to twenty, or forty miles away, it is probable water will likewise exist in the artesian wells. Could a sufficient number of wells be drilled, and could the flow be continued from all of them a sufficient length of time, it seems reasonable to suppose that a diminution in the supply of water on the uplands would first be observed, and later that in the valley. It is probable the small area, less than one hundred square miles, in the artesian valley, and the valley of Crooked creek below Meade, could drain the whole of the uplands to the west, and that their supply of water would not become exhausted so long as there was any available water anywhere in the broad plains to the west or northwest. We are, therefore, brought to the question of the consideration of the amount of this underground water, a subject which is discussed later in this Report. It is sufficient to say here that in the judgment of the writer, water enough could be obtained, were it properly husbanded, to irrigate such parts of the Meade artesian valley as anyone is likely to want to irrigate during the next half century.

Origin of the Tertiary Ground Water.

This question has been discussed by scientists and citizens of Kansas perhaps more than any other one in connection with the "underflow" investigations. Hay, Follett and others have strongly contended that the "underflow" is entirely dependent for its source upon the precipitation on the great plains. Follett, as an engineer, based his argument principally upon the slowness of the movement of water in the sands and gravel. He has expressed such ideas in different places, but perhaps the most concisely and systematically in a paper read before the National Irrigation Convention at Denver, in September, 1894.[1] But he largely neglected the influence of the irregularity of the surface of the Cretaceous floor, and the known great variation of the character of the sand and gravel, conditions which appeal strongly to one familiar with the geologic conditions of the area considered. Hay,[2] as a geologist, approached the subject from a different standpoint. Recognizing that the Cretaceous materials above the Dakota sandstone are practically impervious to water, he contended that the outcropping of such formations along the great divide east of Denver, which trends parallel to the mountain ranges for a considerable distance north and south, effectually shut off all drainage waters from the mountains. In illustrating this view he published a cut (figure 12 of his report) showing how the water of the Denver basin between the mountains and the divide necessarily, as he thought, could not reach eastward through the Tertiary sands. On the other hand, the citizens throughout the Tertiary areas of Kansas "almost as one man" have an unshaken faith that the waters precipitated along the eastern slope of the great Rocky Mountains very largely pass eastward and constitute at least an important proportion of the great body of water which they very well know exists in such vast proportions.

The writer approaches this subject with an appreciation of the difficulty either of saying anything new, or of being able to please anyone by what he may say. It has seemed to him, however, that there are certain fallacies in the arguments set up by the advocates on both sides of the question. He hopes to be able, in a few words, to call attention to a few of these fallacies and to show how, on the one hand, the local rainfall over the great plains is sufficient to produce much greater results than is generally conceded by the citizens; and, on the other hand,

[1] Official Proceedings Third Irrigation Congress, Denver, 1894, pp. 34-38.
[2] Senate Ex. Doc. 41, 52d Cong., 1st session, Vol. IV, part 3, pp. 1-39.

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how that possibly after all a few defects may be found in the premises taken by the opponents. It may be stated at the beginning that it is believed a large proportion of the water comes directly from the precipitation on the plains, a proportion which perhaps can never be accurately estimated. On the other hand, it is believed to be a possibility and a probability that a portion of the water traveling eastward from the Rocky Mountain area is disseminated throughout the general Tertiary of the plains and constitutes an integral part of the Tertiary water. How well such views can be maintained will be seen in the following.

Local Rainfall.—Soon after the State Irrigation Board was created the writer, in speaking with a friend, expressed a desire to be in the great west during some of the heavy rainstorms about which he had heard, in order that he might see for himself the extent of the rains and the general conditions which result. He is now ready to report that his desire was gratified, even to a much greater extent than he preferred. It rains in western Kansas and on the great plains. By this is not meant a little shower barely sufficient to lay the dust, neither is an all-night's rain aggregating two or three inches of precipitation referred to. But it is meant that water pours down from above, recalling to the traveler on the plains the time of old of which it is said "the windows of heaven were opened." Four, six, eight, and nine inches of precipitation have been known within a week. Little arroyos scarcely noticeable in ordinary times, mere ditches in the broad surface, are changed as by magic into swollen torrents. The whole surface of the country becomes a lake, a "water sheet" in the true sense of the term, which flows from the uplands down into the valleys, inundating everything before it.

In July, 1895, three different nights within less than a week's time the little town of Syracuse, in the Arkansas river valley, 15 miles from the Colorado line, was flooded, not by waters from the Arkansas river, but by the "sheet water" flowing off the hills in its journey to the river. The last night of the three the water covered the whole valley to a depth of from 2 to 6 feet, forming almost a continuous lake from the vicinity of Coolidge to below Hartland. Nearly every building in Syracuse had water over the first floor. It was 5 o'clock the next day, nearly 20 hours after the floods first came, before the streets were sufficiently freed from water for a footman to be able to pass from the hotels to the depot without wading. A portion of the platform at the Santa Fe passenger depot was lifted from its place and lodged across the railroad track. Emigrants camping in the valley at different places were obliged to take refuge in their vehicles in the middle of the night, with water two or more feet deep on the ground beneath, and await in darkness for whatever fate might befall them. What the total rainfall was on this occasion in that particular locality is not known, but it must have been 4 or 5 inches. It followed two other heavy rains which had thoroughly saturated the ground and produced similar floods, only much less in extent.

During this same week Bear creek, to the south of the Arkansas river, a stream usually entirely without water nine-tenths of the year, was out of its banks nearly the whole time. To properly understand the conditions here a few words must be said in explanation. Bear creek rises in southeastern Colorado, passes across the Kansas line, and ordinarily entirely disappears in the sand hills south of Hartland. Throughout a part of its course it has a channel with a bank on either side, but in the vicinity of Hartland the banks greatly diminish in height until they entirely disappear, and the channel of the stream, a hundred miles or more in length, simply cease to exist. On this particular occasion the rains in eastern Colorado and western Kansas produced a great flood in Bear creek. The

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following description is taken from a letter received from Judge W. E. Hutchison, of Ulysses, Grant county, Kansas:

"During the night of the 19th of July, 1895, the water rose in Bear creek, about the line between Grant and Stanton counties, and proceeded slowly towards the end of the channel on the edge of the sand hills, near the Arkansas river, south of Hartland. The amount of water was such as could be retained within the channel of the stream, and not more than has often been seen in the channel of this creek once every two or three years. By the morning of the 21st of July the water had almost subsided, but it was reinforced by the heavy rains in Colorado, and commenced to rise again on the 21st of July, and continued to run until the 25th. From the places where it broke out from the channel, most particularly which were near the Grant and Stanton county line, the water flowed in northeasterly and southeasterly directions out upon the high lands. The average depth in the bed of the stream was about six or seven feet; that on the high lands would average about 12 inches. It spread out on each side of the stream one and one-half to three miles, carrying with it drift of all kinds that passed down the channel, particularly grass, weeds, sage-brush, etc. It seemed to run over the high lands as if in a newly made channel. The overflow in the southeasterly direction, near Shockeyville, Grant county, continued as in a channel, in which the current was very apparent for 8 or 10 miles, spreading out on either side of the well-defined and recognized center or channel. The velocity in these channels out on the high lands was nearly equal to that in the main channel for a distance. It was at least on an average from a mile and a half to two miles an hour. The velocity of the water in the main channel was probably three miles an hour. Bear creek has a well-defined channel from the state line to the sunk well at the south side of the sand hills, seven miles south of Hartland. This well, which is simply a depression in the sand hills, and in coarse sand, was never known to have been dry until about two years ago. The level of the water, however, in this depression is usually about six feet below the bottom of the channel at that place. From the sunk well on through the sand hills is a winding channel, which one would scarcely think was intended for a channel of a stream until he should see water coursing through it, as we did this summer. The water ran past the sunk well—the usual terminus of the stream in times of ordinary floods—clear through the sand hills to the last ridge of them next to the Arkansas river, through which ridge there seems to be no opening whatever for its escape. It spread out east and west in irregular shapes, as it could find openings between the ridges of the hills for probably a mile and a half or two miles wide, and it is safe to say was in some places 15 to 20 feet deep, as is now made very apparent by the marks washed out and the drifts left on the sides of the hills. Not a drop of the water escaped into the Arkansas, and after the 25th of July, when the flow down the channel ceased, the water stood and remained in the channel and elsewhere in the sand hills, the same as it did in the basins and lagoons on the uplands. It was not long, however, in drying up in the main channel of the stream. Out on the uplands, especially in basins, the water stood for several weeks. In the sand hills there is water standing now (December 27, 1895,) in some places. Eleven years ago there was a similar overflow of Bear creek, which spread over the uplands, we are told by the cattle-men who were then in this country, and ran past the sunk well into and nearly through the sand hills, as at this time."

A similar condition existed with the White Woman north of the Arkansas river. The rains were not quite as heavy in that part of the state, but they were sufficient to cause the stream to be flooded and pour immense quantities of water into the basin at its mouth, a shallow lake in rainy weather, but ordinary dry upland throughout the greater part of the year. It is useless to continue these descriptions further. The rains of the past two seasons were sufficient to demonstrate to any one familiar with the conditions in western Kansas that during such seasons, the quantity of water precipitated over the Tertiary area which ultimately reached the underground water must be exceedingly great. A considerable portion of the whole Tertiary area is covered with sand, into which the water penetrates with great readiness. Other portions have the mortar beds exposed over them, a porous rock mass which absorbes water almost as readily as the loose sand itself, while the general plains marl, even in its best developed form, absorbs water perhaps as readily as ordinary soils in more humid regions.

To sum the whole matter up it may be stated as an approximation that upon the average, year after year, from four to five inches of water penetrates the ground and joins the ground-water. This is not uniform, for the rains are not

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uniform, and the absorptive powers of the surface vary greatly, so that it is possible for some areas to absorb but little while others absorb large quantities.

Mountainous Water.—In considering this subject it is not necessary to antagonize any statements of fact made by Hay or others regarding the geologic conditions of the great divide east of Denver. It is well known that at least two great streams, the Platte and the Arkansas, pass eastward from the mountainous region. It is equally well known that their banks and bluffs are not particularly high and that in many places there are opportunities for water to work its way laterally from the streams to the main uplands farther east. For the descent on the surface is so great that a level from the bed of the river would have to be carried but a few miles east to have an elevation far above the highest uplands. It has already been shown that the cretaceous floor was greatly eroded in pre-Tertiary time. It has been proved many times from the experience in well-drilling and otherwise that there are underground valleys in the cretaceous floor which do not at all correspond with the surface valleys. Therefore we are in ignorance regarding the condition of the upper surface of the cretaceous near the mountains except where it is exposed, and the slight evidence gained from the various wells which are by no means numerous in that part of Colorado. It is here simply contended that in addition to the two great streams which pass to the east from the mountains there may be other outlets, not for the surface water, but for the underground water, so that much of the precipitation in the mountainous region, which is heavier than on the great plains, may slowly but surely work its way eastward and commingle here and there with the underground water produced by local rainfall.

Another fact of considerable interest in this discussion, and one which seems to have been overlooked by all previous writers, is the relation of the Tertiary to the Dakota sandstone beds in the southwestern part of Kansas and southeastern Colorado. We now have a series of artesian wells along the Arkansas river valley reaching almost continuously from the foot of the mountains to the western border of Kansas. It seems to be well established that they draw their supply of water from the Dakota sandstone, which extends in wave-like forms from near the foot of the mountains eastwards to beyond the middle of Kansas. In southwestern Kansas and southeastern Colorado over an undertermined area it is known the Dakota and the Tertiary come directly in contact and must necessarily therefore mingle their waters. This is true over a large part of Grant county, probably all of it, and over Stanton county and Morton county. The Benton limestone occurs at the surface in southeastern Gray county and was reached in a well at Santa Fe, Haskell county, showing that the Benton reaches south from the river and covers part of that territory. But we have an area of at least three thousand square miles over which it is probable the Benton limestones and shales do not occur, leaving the Tertiary underflow and the water from the Dakota sandstone to commingle and form one continuous mass. In this way, if no other, it would seem without doubt that at least in the southern part of the state the local rainfall and the mountain flow become united in one. In how many places in Colorado the Dakota is brought up to near the surface so as to mingle its waters with the Tertiary underflow we do not know, but probably the commingling of waters is assisted in this way.

Amount of the Underground Water.

No one knows the amount of the ground water, and it is doubtful if anyone ever will. However, a great deal is known on the subject. We have hundreds, yes perhaps thousands, of wells drawing water from it. Some of them have been

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exhausted, while others have been pumped from as rapidly as a 12-horse power engine could operate without producing any appreciable effect upon the amount of the water the well could yield. It is difficult to judge of the capacity of a well even by such operations as these. Should a well reach an underground ridge of the Cretaceous floor it may be entirely barren from the start. Two of the state wells drilled are of this kind. Yet all they demonstrate is that they chance to be located over a ridge in the floor, an island so to speak in the underground lake. Should a well be sunk into an underground valley where the water-bearing sand is a hundred feet thick, the water pumped for a year at the rate of a thousand gallons per minute, it would by no means show how great the ground water is, even in that locality. Should the well become exhausted by the pumping it might mean that that particular pool of water was exhausted, but most probably it would mean that the pump had drawn the water faster than it could flow through the adjacent sand in order to reach the well.

But we know there are vast quantities of water. Hundreds upon hundreds of wells have been pumped from as continuously as the wind would give motion to machinery for from one to five years without showing any indication of a diminution in the supply.

Our estimates of the amount of the ground water, it would seem, must be based upon results obtained from two lines of investigation, neither of which can ever be made exhaustive. One of these is the amount of water which can actually be lifted to the surface from below. The limitations of this means of investigation have already been stated. It will be understood by all thinking people that the only way the question could ever be answered by this means would be to have a sufficient number of pumps to entirely exhaust the supply of water, which is impracticable, and equally undesirable were it practicable. The other line of investigation is to determine the source of the water and to form an estimate of the amount in that way. This, too, has already been shown to be impracticable if an exhaustive inquiry is desired. It would be difficult to estimate, excepting approximately, the proportion of precipitation on the great plains which reaches the underflow. But it is much more difficult to determine the amount of water available from other sources. Should this be confined entirely to the Dakota sandstone, which, as already stated, is not probable, no way is known at present of determining even approximately the amount of available water.

It should be remembered that we have here a means of concentration which is very effectual. The limited precipitation of western Kansas, averaging from 15 to 20 inches per annum, varying with location, would be entirely evaporated were it continuously exposed to the surface.

But by the methods employed by nature a considerable portion of this precipitotion soon passes downward beyond the reach of evaporation. On the basis of 12 inches of water being all that is necessary to add each season, if 6 inches of water annually joins the underground water it would be possible to irrigate 50 per cent. of the whole area; if 3 inches of the rainfall is saved annually 25 per cent. could be irrigated; while if only 1 inch annually of the rainfall is saved 8⅓ per cent. of the whole territory could be irrigated.

While discussing the Dakota artesian water supply it was urged that the most important question is the rate of supply rather than the amount now accumulated in the underground reservoirs. Here the argument is equally forcible. The volume of water now stored in the Tertiary sands and gravel can be of only temporary interest, can serve only temporary wants. It is the annual addition to the available water which is of the greatest importance, for it represents the amount which can be perpetually used each year.

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When we consider the relatively large areas in western Kansas covered by surface sands which absorb almost all the precipitation, and the large number of small streams which pour their water out upon the sand hills and uplands during the times of freshets, it seems reasonable to suppose that an amount of water is saved annually equal to from one to two inches for the whole area. This alone, if properly handled, would irrigate from 8 to 12 per cent. of the whole country, which is probably more water than the ground will be called upon to furnish for several generations. Add to this the probability of additions of water from other soudrces, and we have a supply of water awaiting utilization which probably is as great as need be desired at the present time. The important question now is not: How much water can be obtained from the great plains? but it is rather: How can the existing ground water be drawn to the surface? and: How can it best be used when obtained? In the light of the investigations made during the past two seasons, the writer considers these the only vital questions at the present time in connection with the reclamation of western Kansas.

In this connection the accompanying hydrographic map should be carefully studied. It will be seen that large portions of the whole area have water within less than 75 feet of the surface. To the areas thus represented on the map should be added the valleys of many lesser streams which could not well be shown here. Were all these areas inhabited with agriculturists, farming by the most approved methods of recent intensive farming, to as great an extent as the available water would permit, western Kansas would support a very respectable population. As the water is drawn from those areas until a degree of exhaustion is almost reached it will pass in from the other areas from which the water is not lifted. In this way, to a considerable extent, water may be drawn from the high uplands where it lies so far below the surface that pumping is exceedingly expensive.

Discussion of Special Areas.

General Upland Areas.—It is now proposed to make a few remarks regarding the conditions of special areas, beginning along the north side of the state and passing southward.

One of the most peculiar, and at the same time most interesting areas in the state, is that of Jewell county. It will be seen by referring to the geologic map that a long narrow tongue of the Tertiary formation extends along the north side of the county to the Republican river, occupying the high ridge between the Republican river on the north and the White Rock on the south. The Cretaceous chalk beds are exposed along the White Rock almost entirely across the county, and also along the bluffs of the Republican, but on this divide the whole of the formation to a depth of about 100 feet is Tertiary. A cross section of the Tertiary ridge taken from the surface contours and the records of various wells (see figure 10) shows that the Tertiary ridge rests in an old Cretaceous trough. The evidence for this is strong. At one place just south of the Tertiary, and immediately north of Mankato, a well was drilled to 90 feet, passing through the chalk beds the entire distance, excepting the light surface soils. Less than a mile away to the north, on about the same surface level, another well was sunk 95 feet, passing the whole of the distance in the Tertiary, which found an abundance of water before the chalk beds were reached. The whole belt is full of wells, usually nearly 100 feet deep, every one of which furnishes a large supply of good water, while along the Republican brakes to the north, or the White Rock to

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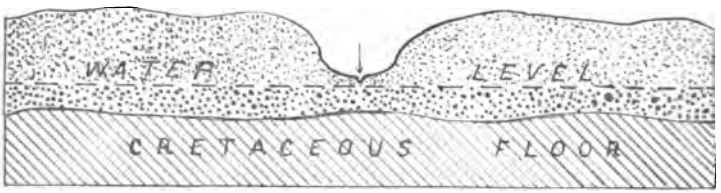

Fig. 7.

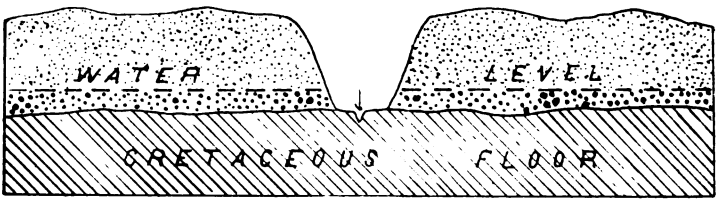

Fig. 8.

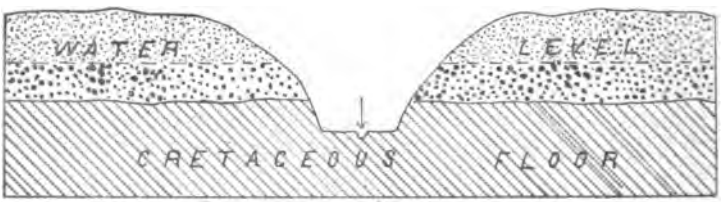

Fig. 9.

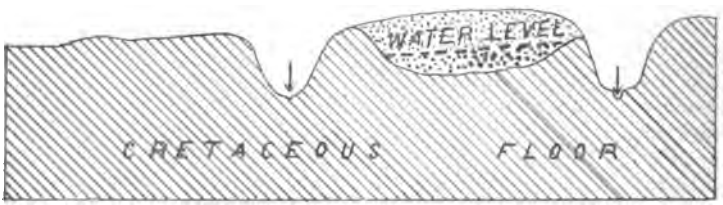

Fig. 10.

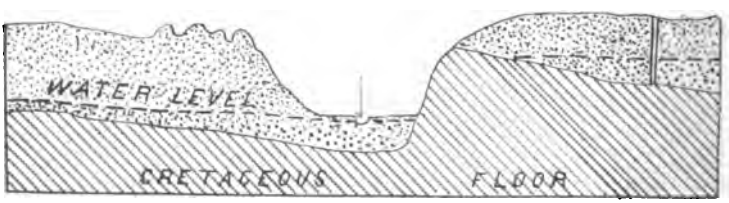

Fig. 11.

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the south, water is hard to obtain by digging, and that which is procured is so mineralized it is not very serviceable. Another evidence favoring the idea of a Cretaceous trough under the Tertiary ridge is the condition of springs. Scarcely a spring is known along either side of the belt throughout Jewell county, but at the eastern end of the area, along the bluffs of the Republican river, springs are numerous, the supply of water they furnish is abundant, and the quality is the same as that produced by the wells in the Tertiary area.

Passing westward from Jewell county through Smith and Phillips it is noticed that in a number of small areas the Cretaceous rocks are exposed to the surface. Obtaining water in these counties is therefore rather uncertain for those who prospect regardless of the geologic conditions. But so far as learned wherever a well has been put down to the proper depth in localities where the Tertiary deposits had any considerable thickness, water of good quality and lasting quantity was invariably obtained.

Still farther west in Norton county and the northern part of Phillips larger portions of the surface are composed of the Cretaceous chalk beds, while the two forks of the Solomon river and the various lesser tributaries usually cut down through the Tertiary to the Cretaceous and sometimes far within it. The obtaining of water is therefore somewhat uncertain in those two counties, but the outlines of the Tertiary formations, as shown on the map, may be used as a guide.

Still farther west in Decatur and Rawlins counties the Cretacous deposits are relatively thick and the wells are correspondingly deep, but in almost every case the supply of water is abundant and the quality good. Some of the tributaries of the Republican in Rawlins county have cut their channels downward through the Tertiary, and for some distance into the Cretaceous, giving areas where the water supply is deficient. But while this result has been produced another one exceedingly advantageous has also been brought about. The streams cutting through the Tertiary to the Cretaceous floor have made it possible for springs to exist, the conditions for which have already been explained in preceding pages. It is by no means uncommon in Rawlins and Cheyenne counties, particularly in the latter, to find various valleys along the principal tributaries of the Republican which are well watered the year round without any artificial application. The valleys have been corraded to the base of the Tertiary and an outlet to the general body of underground water has been produced, so that constant seepage is in progress forming pools of living water here and there along the streams, and frequently saturating the soil of the valleys to so great an extent that even in dry seasons further application of water is not desirable.

Cheyenne county is interesting to the student of the water problem on account of the great diversity of conditions existing. It will be seen that in the central part of the county, and again to the northwest and north, certain areas of Cretaceous rocks are exposed. Even in the very center of the county, at St. Francis, a small shale area exists sufficient to interfere materially with the production of water. Few counties in the state have had more wells drilled in them than this, and it would seem that in few localities have the people been more determined to obtain water from the Cretaceous shales than here. But in almost every instance it has proved a failure. In the few cases where success has followed their efforts it has probably been due to fissures in the shale leading off from the Tertiary water. From the evidence given by the wells it would also seem that the surface of the Cretaceous floor is more irregular here than in most localities. Stories are told of wells only a few yards apart, one of which is confined wholly to the Cretaceous, while the other is confined wholly to the Tertiary.

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Passing southward from the border tier of counties, the high divide between the Republican and the Smoky Hill river is encountered, and so far as the available evidence shows water exists in the greatest abundance over the whole area. Sherman county, Thomas county, Sheridan county, and the greater portion of Graham county and a considerable part of Rooks county possess similar conditions. The prospecting for water has been carried to a greater extent in Sherman county, perhaps, than in either of the others named. The depth to the water varies slightly on account of the varying conditions of altitude of the surface, but in most places water is reached at from 150 feet to 200 feet, and frequently will rise quite perceptibly in the well. It is not unsuual for the drill to find a bed of water-bearing sand above a stratum of clay, below which is another bed of water-bearing sands the water in which will rise to the level of the first water reached. Some wells even have passed a third water-bearing stratum before the Cretaceous floor was reached. A neck of the Cretaceous shales exposed along one of the tributaries of the Smoky Hill passes up into the southeastern part of Sherman county, producing an area in that part of the county over which water is hard to obtain.

The third tier of counties from the north line, including Wallace, Logan, Gove, and Trego counties, has a much greater variety of conditions than prevails to the north. The Smoky Hill river and its principal tributaries have cut their channels through the Tertiary, but only a short distance into the Cretaceous, and have accumulated so little sand and silt along their valleys that there is but little ground water in the river valleys proper. In this area perhaps more than in any other part of the state we have the apparently anomalous condition of water being hard to obtain by digging in the river valleys, yet easily obtained in great abundance on the high uplands near by on either side of the river. A discussion of the causes for this set of conditions has already been given. But along with this absence of water by boring a few favorable conditions are mingled, the existence of numerous springs. This is implied by the geographic terms, such as Sharon Springs, in Wallace county, and Russell Springs, in Logan county. Where the base of the Tertiary is reached by the Smoky Hill or its tributaries water from the general underground supply is frequently found producing never failing springs of good, fresh water.

In many parts of these counties, however, an abundance of water is obtained, both north and south of the Smoky Hill river. In Wallace county water is found so far as is known almost without exception where the Tertiary has any considerable thickness. In Logan county it also exists in great quantities, and many of the nicest irrigated gardens and small fields found on the uplands in the state are nestled around the railroad stations in the northern part of this county. The experiments at the state well at Oakley given by Judge Sutton show something of the large amount of water here.

Eastward in Gove county and Trego county the water is not so abundant, and boring for it in the Tertiary areas is not so sure of favorable results. The state well located at Wa Keeney, Trego county, although producing water sufficient in quantity, perhaps, to supply the demands of the ordinary farmer, was reported a failure by the Board because it was not sufficiently productive to be of any considerable importance in irrigation. At this place the water-bearing sand was but 4 to 6 feet thick, and exceedingly fine grained, so that the flow of the water through it would be unusually slow. Beneath the sand, at a depth of approximately a hundred feet, the Niobrara chalk beds were reached, showing that it

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was useless to go any farther. This tier of counties is the area farthest north, so far as the writer is informed, which has been prospected by deep borings and which has so uniformly yielded salt water from the Dakota sandstone.

The next tier of counties to the south, or the fourth tier from the north side of the state, comprising Greeley, Wichita, Scott and Lane counties, has but little exposure of cretaceous rocks, yet the evidence obtained from various wells, particularly along the line of the Missouri Pacific railway in Greeley county, shows that there is a great underground ridge of the Cretaceous floor, in many places coming to within 50 or 75 feet of the surface, with little water above the underground ridge. This part of Greeley county is one of the most unfortunate areas in the state in this respect, yet it appears on the map to be completely covered with the Tertiary formations. In places the water is relatively abundant and of good quality. One of the worst features of this condition is that there is practically no indications on the surface where water can be obtained and where it cannot. It seems to be almost wholly dependent upon the existence of ravines and channels in the surface of the Cretaceous floor, the existence of not one of them being indicated at the surface. The state well at Tribune, in the valley of the White Woman, reached the Cretaceous floor without passing through any water-bearing sand, while other wells near by on the highest ridges of the county found large quantities of water.

The state wells at Leoti and Dighton were more fortunate. Private wells also show that these counties are much better watered than Greeley county. As far as we can tell many parts of these three counties are well watered.

Eastward in Ness county there is a similar Tertiary area down in the valley of the Walnut which uniformly affords water, apparently in great quantities. Here also are found several wells which have penetrated the Dakota sandstone and have succeeded in obtaining good, fresh water in large quantities. The experience of those who have drilled deep enough to reach the Dakota would indicate that throughout this part of the country no one need doubt the widespread distribution of Dakota waters in this locality, so, that in connection with the Tertiary water and the Dakota water, the Walnut river valley, throughout its entire course, is one of the best watered portions of the state.

Passing southward from this tier of counties we are taken to the Arkansas river area. Here we have two sets of conditions, the river valley proper, and the uplands on either side. The northern part of Hamilton, Kearny, and Finney counties may be influenced by the great underground swell in the Cretaceous floor already mentioned as occurring farther to the north. Many wells have proved failures; but the country is so sparsely settled that Mr. Adams and Mr. Patten found great difficulty in obtaining much reliable information for that part of the country. The state well five miles north of the river almost on the border between Hamilton and Kearny counties, at a depth of 172 feet reached water-bearing sand more than 20 feet in thickness. On the uplands on the south side of the Arkansas river in these counties but little prospecting for water has been done near the river, as the whole surface is covered with sand dunes for several miles away. Such wells as have been sunk, however, have uniformly found water. The state well near Cimarron is a good example of this. Dug on the uplands in the sand-hills area, after passing through sand and clay a bed of unusually coarse gravel was found which seems to contain more water than any ordinary pump will be able to lift.

The Arkansas River Valley.—The Arkansas river valley, viewed from the water standpoint, is one of the most remarkable areas in America. We have re-

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liable evidence showing that in past time the river cut a wide and deep channel into the Cretaceous floor, which is here the Benton limestones and shales. It seems that on the south side only slight banks or bluffs existed, if any at all, while on the north they rose to perhaps hundreds of feet in height. Subsequently, the channel became filled with gravel, and sand, and silt almost to the level of the banks on the north. Figure 11 represents these conditions. The Benton limestones and shales are exposed in the bluffs at the present time from Hartland to Coolidge and beyond, while they are usually less than 100 feet under the surface over the greater part of the upland for miles to the north of Garden City. Northeast only a short distance they appear at the surface. On the south side of the river, however, the conditions are very different. Not a well heard from east of Hartland raached the Cretaceous floor, and but few of them in the southern part of Hamilton county found it. Farther to the southeast, in the southeast corner of Gray county, a small exposure of Benton is known, so that probably wells in central Gray county would reach the same rocks at relatively shallow depths. It would seem, therefore, that the Arkansas river in some way in earlier times succeeded in cutting its channel in such a manner that high, steep bluffs were produced on the north with almost no bluffs whatever on the south. A discussion of how this could be brought about is purely geologic, and would be somewhat out of place here.

The maximum depth of the river channel in past time is not yet known. Many reports were made by individuals concerning the subject. Unfortnnately the records of the artesian wells at Cooledge seem to be destroyed. Some parties told the writer that the shale was reached at about 30 feet in the river valley at that place, while others said that it was much farther. Eastward it seems that the thickness of the present sand in the valley is greater, reaching from 100 to 200 feet thick. We therefore have undoubted evidence that the valley of the Arkansas river was at one time much deeper than now, that this valley has been filled in with sand and gravel and silt brought principally from the west, but partially from the adjacent Tertiary deposits, and that the whole river valley with its hundreds of feet of sand and gravel to-day is a great mass of water, or underground lake of water, which is moving slowly eastward, but which can be obtained by boring almost anywhere within the valley to a depth not exceeding 15 feet, while in most places the depth varies only from 6 to 10 feet. The amount of this water cannot now even be approximated. In different instances wells have been put down only a few feet into the water, steam engines attached to the pump and water pumped at the rate of from 500 to 1,000 gallons per minute with no appreciable effect upon lowering the water level in the well other than might be attributed to a slight depression in surface due to tha necessary slowness with which the water could move through the sand to the well from all directions.

In addition to the ordinary ground water in the Arkansas river valley, we have the Dakota waters in the Dakota sandstone existing in great quantity and at obtainable depths, as was discussed at length while speaking of the Dakota water. These two kinds of water combined make the Arkansas valley of the best watered parts of the world.

The next tier of counties southward — the sixth from the north — includes a large territory which yields an abundance of water. Throughout the greater portion of Stanton county and the western part of Grant county the Dakota sandstone comes so near the surface that the depth to the water is not very great, perhaps averaging less than 100 feet. Eastward, in Haskell, and parts of Gray county, however, the depth is greater, as shown on the hydrographic map plate.

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Still farther east, in Ford county, an abundance of water is obtained at from 50 to 150 feet, while the same water area exists in Kiowa and Pratt counties in undiminished quantity.

In the southern tier of counties, including Norton, Stevens, Seward, Meade, and Clark counties, in addition to the ordinary ground water two other features are of special interest. The Cimarron river valleys aggregate about 250 square miles of unusually smooth, even land, with the water in great quantities lying at a depth of from 10 to 30 feet. In a few cases greater depths have been passed before the water was reached, but quite frequently in such instances it has risen in the well to within 20 or 30 feet of the surface, so that this measurement represents the distance the water will have to be lifted in pumping. The wells have not been tested to a sufficient extent to warrant a positive opinion regarding the amount of water they would furnish, but from other conditions no doubt can be entertained regarding its abundance. The South Cimarron rises away towards the mountains, and usually has a freshet every summer entirely independent of the local rainfall.

A second subject of special interest here is the Dakota water which is so shallow, which can be reached at such shallow depths in the southwestern part of the state. In places it comes to the surface, as shown on the map, elsewhere it is within a few hundred feet of the surface. Probably wherever reached it will produce large quantities of water.

The McPherson Area.— In the vicinity of McPherson exists an area remakable in its geologic properties and very important in connection with the underground water which it conveys. In past time it seems an old channel similar to a river channel was worn connecting the Arkansas with the Smoky Hill river, and covering a width in some places of about twenty-five miles. This area is represented on the map, Plate XIX, by obliquely ruled lines and light stipples.

By an examination of this map it will be seen that it covers all of the surface from the Smoky Hill south to the general lowlands of the Arkansas river, including the area around McPherson, Groveland, Elyria, Mound Ridge, Halstead, Burrton, and other places. On the east it passes within about two or three miles of Newton, and a like distance of Lehigh. From this point it bears rapidly to the northwest until the Smoky Hill river is reached. Aiken is near the western boundary, from which point it bears south until the general lowlands of the Arkansas river are reached to the northeast of Hutchinson. Plate XX shows four sections across the area, the locations of which are marked on the map. By an examination of these sections it will be seen that the covering of sandy material is relatively thin throughout the main part of the eastern area, but that near the western side the sand increases in depth to nearly 200 feet. How much deeper the old river channel was is not known, as the original floor of the channel has not yet been reached by any of the wells in the locality.

The important feature of this area in connection with the present discovery is the unusually large supply of good, fresh water which it provides. The whole area is supplied with an abundance of water which is, in almost every respect, similar to the Tertiary ground water of the west. The city well at McPherson is a good illustration of the amount of water which can be had. This well reached a depth of about 140 feet, and obtained a supply of water so great that the constant running of the large pump in the 10-inch well could have no apparent effect upon it. It is described by Dr. S. Z. Sharp as follows:* "Here the water is obtained in abundance at 100 feet. The well of the city water-works is 140 feet

* S. Z. Sharp, unpublished paper read at 1895 meeting of Kansas Academy of Science.

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deep, and the water is pumped through a 10-inch pipe by steam into a stand pipe. When the water-works were constructed eight years ago and put to a test, previous to their acceptance by a stock company, the pump was kept running continuously for 10 days, lifting 10,080 gallons per hour."

The economic importance of this water supply cannot be overestimated. It is easily seen by an examination of the surface of the country during the summer season that the general farm crops throughout this whole area are more flourishing than on either side. The artificial groves of different kinds of trees, and the orchards of various kinds of fruit-trees, show a marked difference in health and rapidity of growth. This is so strongly marked that one standing on a prominent ridge on either side of the area in midsummer can trace with the eye the boundary lines of the area by the different appearance of vegetation here and elsewhere. It is not overstating the conditions to say that year after year the average yield of crops in this locality is decidedly superior to the yield on either side. In addition to this the farmers and citizens throughout the whole of the area have within easy reach an abundant supply of water which is suitable for all kinds of domestic purposes, and which is sufficient in quantity to meet any demand that may be put upon it. The city of Newton at present is arranging to obtain its water supply from wells bored six or eight miles to the west of the city, located in this same Pleistocene sandy area, or old river valley.

At present it seems that there is here an underground water connection between the Arkansas and Smoky Hill rivers.

For a further discussion of the geologic conditions of this most interesting and remarkable area the reader is referred to a description of the same under the name of the McPherson Equus Beds, by Mr. J. W. Beede, in Vol. II of the University Geological Survey of Kansas.

Special Areas Described by Dr. Geo. I. Adams.

Jetmore to Larned—The Valley of the Buckner and Pawnee Rivers.—The investigation of this area extends a distance of 50 miles along the Pawnee and Buckner to Jetmore. It covers a strip 12 miles wide, conforming to the government townships, beginning at Larned, in towns 21 and 22, and jogging south to Hanston to towns 22 and 23. The area embraces approximately the valley of the above-mentioned streams, extending well upon the divides on either side of them.

The geology of the area is easily comprehended. At Larned we have a typical exposure of the Dakota formation in the hill on which the town stands. The valleys of the Arkansas, Pawnee and Ash creek at this place are eroded into the Dakota, and outcrops are found in many places on the margin of the bottom lands. Along the Pawnee the Dakota extends beyond the limits of the area here described, and along the Buckner for a distance of three miles beyond the confluence of the Saw Log with that stream. It is well exposed in the valley of the Saw Log and as far south and west as Duck creek. Opposite Hanston there is a good exposure of the shales and clays, intermingled with some sandstone. The formation is for the most part covered with later deposits of sand, clay and gravel in the valley of the stream, so that its appearance on the surface is confined largely to a strip bordering the creek bottoms.

The Dakota formation is the lowest one exposed in this area. As the slopes of the hills are ascended, or as we proceed up-stream, we find it superseded by the Benton. This formation is readily recognized by the character of its rocks and shales, as has already been described. The area over which it is found out-

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cropping, as is shown on the map, Plate XXIV, is an irregular V-shaped figure, embracing the Dakota of the east and extending westward beyond Jetmore for a distance of twelve miles, narrowing rapidly to the immediate valley of the Buckner. Its thin limestones, yellowish and bluish shales are easily recognized and distinguish it from the Dakota. A very prominent horizon of this formation is the one which furnishes the post stones quarried around Jetmore. Before the Tertiary was laid down the Benton was eroded considerably so that its eastern edge is very thin. The Tertiary originally having a wider extent than the Benton is thus found in some places to rest upon the Dakota, as is seen in the northern part of Edwards county, where the Benton area narrows to a point. In the valley of the Saw Log it can be seen from the mapping that the Benton is not represented between the Dakota and the Tertiary a short distance south of the confluence of this stream with the Buckner.

Above the Benton is found the Tertiary formation on the divide south of the Pawnee which extends within a few miles of the city of Garfield, being represented there, however, only on the tops of the hills. It is found covering the divide southeast of Morena. Its extent to the west is interrupted by the valley of Saw Log creek. West of this creek it forms the high level ground of the divide south of Jetmore. On the north side of the Pawnee its formation is very limited, its extent being confined to the few irregular patches on the highest hills between the Walnut creek and the Pawnee, situated beyond the limits of the area here described in particular. North of the Jetmore it is found on the high lands which constitute the divide between the Buckner and the Pawnee Fork. In the western part of Hodgeman county, where the Benton narrows to a point along Buckner creek, the Tertiary is found approaching the immediate valley, so that it is the only formation represented on the head waters of that stream. The Tertiary formation consists, as already described, of sand and clay mixed with varying quantities of gravel. Its base there is usually a rough stone rock varying considerably in character, being quite well cemented with calcareous material so as to form the rough limestone. Fragments of the Tertiary of sands and gravels and the worked-over clay are found on the slopes of the valleys everywhere along the small streams; but the area of the Tertiary, strictly speaking, is as mapped on Plate XXIV, and this debris belongs properly to Pleistocene deposits, formed by the action of the drainage water in the valleys of these streams. This may be spoken of as a Fluviatile deposit. It is most prominent in the level bottom lands. Its principal area is shown on the map as uncolored, but every small stream and draw contain it and a great many hillsides and slopes are covered by these sands and clays to a considerable depth, making it impossible to see the underlying formations, except where recent cuttings in the stream banks have exposed them.

In the eastern portion of the Pawnee bottoms the width of this Fluviatile material is approximately six miles, embracing the area drained by the Saw Mill creek. This latter stream, although represented on the map as following in a distinct channel approximately parallel with the Pawnee, is in fact not well defined. It contains no water except in flood times, when its meandering course forms a network of shallow streams flowing into the Pawnee, or uniting to form a side channel to that stream at some distance south of it. In many places these channels have the appearance of artificial ditches, their banks being raised considerably above the level bottom lands, and not infrequently the bottom of the ditches being higher than the level of the surrounding land. Where the channel is most distinct it has cut deeply into the Fluviatile material, and often ponds of water remain standing in these deep holes for considerable time after the flood period. This is more particularly true where the branching network unites to

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form a main channel. The thickness of the Fluviatile material along the Pawnee river is approximately 40 feet in the eastern portion of the valley, this being the depth at which many of the wells can reach the so-called river gravel. As the area of the Fluviatile material narrows to the west, it maintains a considerable thickness in the immediate banks of the stream, as at Jetmore, where wells in the bottom reach water in sand at 32 feet. It becomes of little importance westward at the limits of the Benton.

A discussion of the water supply of this area depends upon a general knowledge of the geology of the area. As the character of the formations bear a direct relation to the conditions under which the water may be found, we may consider the subject under the following heads:

First:—The water in the alluvial deposits in the creek bottoms and their smaller tributaries.

This water supply is usually found in the sand and gravel, sometimes in clay. It is most abundant where the bottom lands are widest and the alluvial material thickens. On the hillsides it is confined to the immediate beds of the smaller draws or ravines and often amounts to only a seepage supply. The water is usually good and along the creeks it is never failing.

Second:- The water in the Dakota formation.

This water supply is reached by wells which extend into the clays and sandstones of the Dakota formation. The water is good and soft when reached at shallow depths. When the water is found in the porous sandstone, or the clay, it is usually abundant. When the well penetrates a hard sandstone which is well cemented, the water supply is often scant, although good. The deep wells in this formation often find mineral or salt water, especially in the eastern portion of the area. Many of the wells may be said to be artesian; although not flowing out at the top the water that rises in them stands at a constant level the year around. The mineral well at Larned flows. It, however, reaches a greater depth than it is practicable to bore for fresh water.

Third:—The water in the Benton.

The water found in the Benton is usually limited in quantity, especially when found in shales, although frequently wells which are dug at the level of the limestone find strong veins of water. The water in the Benton is frequently contaminated with mineral materials from the shales, so that it is rare that a well of water is found which is good for house use.

Fourth:--The water in the Tertiary formation.

This is, properly speaking, the principal water of western Kansas. It is usually found on the base of the Tertiary in sand or coarse sandstone, and not infrequently it is found in clays. The supply is abundant. Where the area of the Tertiary is sufficiently great, the level of this water is indicated by the numerous springs which are found issuing from the Tertiary around the borders of that formation, as for example, along Spring Creek southwest of Jetmore.

Fifth:—The water in the Dakota reached by deep wells which pass through other formations.

Where the surface formation does not contain sufficient water, as for example in limited areas of the Tertiary, or where the water is not good, as over the area of the Benton, deep wells are frequently resorted to. These pass through the overlying formations and reach the water of the Dakota. Usually the water rises in the wells and stands at a constant level comparatively near the surface of the ground. This water, in general character, is the same as that discussed under the second head.

Little Walnut Creek Area.—The valley of the Little Walnut extends in the

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southeast corner of Rush county to Great Bend. It widens rapidly towards the east. This valley is confluent with that of the Walnut. It is eroded for the most part in the Dakota formation which, consisting of sandstone and soft shales, has yielded readily to the action of the stream, and as a consequence the valley is broad and the bottom lands quite extensive. The Dakota is found outcropping in a narrow area bordering the bottom lands; but its presence under the alluvial material is shown by the records of the wells which reach it in many places. Toward the head of the Little Walnut the area narrows rapidly, it forms an irregular V-shaped area, which is in turn embraced by the Benton. The Benton forms the high lands of the divide. The section of the valley at its middle portion shows the valley of the stream eroded in the Dakota and on either sides, the Benton upon the hills. Near the head of the stream a section shows the entire valley eroded in the Benton, the presence of the Dakota below being revealed by the deep wells which pass through the overlying Benton.

The Walnut River Valley.—The Walnut river valley, from the vicinity of Ness City where the north and south forks unite, to its junction with the Arkansas river near Great Bend, is eroded in the Benton formation. The valley is broad and quite regular. The stream has comparatively few tributaries which drain any considerable area. The Tertiary formation, which is found only in limited outlying areas on the high plains and the divides north and south of the stream, is practically of no importance in the discusssion of the water supply. Near the mouth of the Walnut the Dakota is found on a narrow ridge of land between the Cheyenne bottoms and the Walnut, and the eastern extension of the divide south of the Walnut is likewise composed of this formation. It has very limited outcrops, however, and the broad valley being filled with Fluviatile material, the surface appearance of the Dakota is not very important. Along the Walnut river we have mainly the Benton formation at the surface. A cross-section in the vicinity of Heizer would show the valley eroded in the Dakota, and filled in with a broad extent of Fluviatile material. A cross-section of the valley further west at Rush Center would show the valley eroded wholly in the Benton. The Dakota is found, however, in deep wells, many reaching it in that vicinity.

At Ness City the Dakota is found at a greater depth, since as we ascend the river we reach the higher horizons of the Benton. Here the wells which reach the Dakota are drilled to a considerable depth, as for example the Shepherd well, explained by Professor Haworth in preceding pages.

The Fluviatile deposits in the valleys of the Walnut and its tributaries are of great importance, as furnishing the principal water supply of this area. The valley of the Walnut is filled in with sand and clays, having a substratum of gravel for a considerable width. The important tributaries of this stream on the south are Dry Walnut, Otter creek, and Old Maids' Fork; on the north, Sand creek, Alexander Dry creek, Bazine Dry creek, and Long's Branch. These likewise have their valleys filled in with considerable deposits of Fluviatile material. The Tertiary, although as before stated is of little importance even on the divide, has however contributed its debris to cover the Benton in the valleys.

The Fluviatile deposits, although not very great on the slopes, are nevertheless of great importance, especially in the valleys, as they are the water-bearing formations. The water supply along this valley may be discussed under the following heads:

First, the water in the Fluviatile material; second, the water in the Dakota; third, the water in the Benton; fourth, the water in the Dakota, reached by deep wells which pass through the overlying formations: fifth, the water in the Tertiary.

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Under this last head may be included only a few wells found on the high divide between the Pawnee and the Walnut. The Tertiary here is found in only a few irregular patches and usually is of not great enough extent to form a reservoir capable of supplying a large amount of water. There are many wells, however, which depend upon it for their supply.

Under the head of the Fluviatile, the water supply of the city of La Crosse should be mentioned. Here we have a town located on a small stream, with the water found in the underflow of its immediate valley, which extends in a comparatively narrow zone through the city. Wells dug on either side of this extend into the Benton and fail to find water.

Ness City to Dighton.—Ness City is situated approximately on the western border of the Benton area. The upper portion of the Benton consists of a thick bed of blue shales containing numerous concretions and Septaria. Immediately above this bed of shales we find the Niobrara. The base of this formation consists of white soft limestone, usually evenly bedded and found in thick strata, so that the contrast between the lower Niobrara and the upper portion of the Benton is very decided. As we go west from Ness City we find a very decided step up from the Benton onto the Niobrara. This is occasioned in the following way: Where the Niobrara overlies the blue shale of the Benton, it forms a protecting cap which prevents its erosion. When this cap is removed, the shales are very readily cut away by the action of the water, so that there is a decided bluff left in which we have an exposure of the shales. This condition of things can be seen in the vicinity of Laird Station, where a typical exposure of these blue shales may be found. The Niobrara thickens to the west. It is in turn overlaid by the Tertiary which is found capping the hills north of the Walnut at Beelerville, as well as on the divide south of that town. The Niobrara has a very limited area, as is shown on the map. A long arm of it extends in the immediate valley of the South Walnut almost to Dighton. The exposure along the creek consists of white soft limestone, light bluish shales, and yellow chalky shales. It is readily distinguished from the overlying Tertiary, which consists of clays mixed with sand and imperfectly consolidated sandstones. The high, level prairies are the areas where the Tertiary is found.

The water supply of this area may be discussed under the following heads: First, the water in the Fluviatile material; second, the water in the Benton; third, the water in the Niobrara; fourth, the water in the Tertiary.

The water in the Fluviatile material along streams is very important. The valleys of the streams are not very important except near the confluence of the North and South Walnut, where there is a considerable area of bottom land; but everywhere along them as well as along the smaller tributaries there is a constant supply of good water, which is reached in the many wells which are dug near them and in the draws which flow into them.

The water in the Benton is practically of no importance, for where it is found in the shales it is usually contaminated with mineral and organic materials and unfit for use. The water supply in the Niobrara is very scant. The limestones with their intervening beds of light-blue, chalky shales do not carry a very abundant supply of water. Wells which are dug into this formation usually have a supply which depends upon the seepage through the porous rocks or occasionally they may strike a vein of water.

The water in the Tertiary is, of course, the underflow water which is so characteristic of the level prairies further west. In this area we are considering only the eastern border of the Tertiary. Wherever limits of the Tertiary area are reached springs are found coming out from under the Tertiary in great abundance.

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Some of them flow constant streams, but the most of the water seems to leak out around the borders of the formation, and finds its way immediately into the Fluviatile material of the draws and creeks and forms their water supply. Many of the more important streams of this area have a small amount of water in dry weather, and by digging into the sand of their beds water will be found in great abundance.

The water in the Tertiary is usually found in sand or clay. Sometimes, however, the wells find water in what is properly called the yellow soapstone below the base of the Tertiary. This is the yellow, chalky shales of the Niobrara, into which the water from the Tertiary can penetrate a short distance.

Big Timber Creek Area.—Big Timber creek is a tributary of the Smoky Hill river, having its headwaters west of McCracken. The divide between it and the Walnut is situated near Big Timber creek so that the south slope of the hill is comparatively short. The divide between Big Timber and the Smoky Hill is low, the principal portion of the valley lying on the north side of the creek. The headwaters rise in a broken area in the eastern limits of the Tertiary and the Niobrara outcrop. The valley of the stream proper is eroded wholly in the Benton. Big Timber creek is supplied with a large quantity of water in flood times, but during the dry periods contains little or no water. Here we have a line of hills in which the Niobrara outcrops. This formation forms a protecting cap to a bed of blue shales which constitute the upper portion of the Benton. When the limestones of the Niobrara are removed by erosion, the bed of blue shales is quickly carried away, and hence we have the resulting step up in the level of the country. The Niobrara here is not very thick. It consists of white limestone, light blue shales and yellowish chalky shales, which may be readily distinguished from the Benton. They are found outcropping on the brows of the hills and in the narrow cañons. The Tertiary is found overlying the Niobrara. Its eastern limit is very irregular, but is approximately parallel to the eastern limit of the Niobrara, so that on the map we have the Niobrara in a narrow irregular strip extending from northeast to southwest. Along the eastern limits of the Tertiary we find springs which flow out from the base of that formation and supply the underflow in the alluvial deposits of the draws and small creeks which form the headwaters of Big Timber. On the level prairies around Brownell and Ransom, which constitutes the top of the divide between the Smoky Hill river and the Walnut, the Tertiary area is represented.

The water supply of the area drained by the Big Timber may be discussed under the following heads:

First. The water in the Benton. This is never very abundant nor very good.

Second. The water in the Niobrara. Good, but never very abundant, since the character of the rock is such that it carries but little water.

Third. The water in the Tertiary around the headwaters of the Big Timber. This supply is usually abundant and the water good, being the typical underflow of western Kansas. It is important where we reach the level uplands on the divide.

Fourth. The water in the Fluviatile material is that which is depended on for that portion of the valley which is situated on the Benton area.

There is a vast quantity of sand and clay deposited on the slopes of this valley, more particularly on the northern slope of the valley and on the divide between it and the Smoky, where the debris and worked-over material from the Tertiary forms a considerable surface covering in which water is found, the water being good and sweet. Wells which are dug into the Benton strike blue shale and some thin layers of limestone and the water is seldom good, since it is contami-

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nated with mineral material and organic substances from the shales. The Dakota formation nowhere outcrops in the area here discussed. Further to the east, as is shown on the map, the Dakota is found outcropping along the immediate banks of the Smoky Hill river. It extends under the Benton and deep wells reach it in many places, so that those who have failed to find water in the Fluviatile material over the area of the Benton have occasionally sunk deep wells to the water found in the Dakota.

Dighton and Ransom to State Line.—The area here described extends from the eastern margin of the Tertiary area westward to the state line. It constitutes the level prairie land of the divide between the Smoky Hill river and the Arkansas, the portion here described in particular being the strip embraced within the government towns 16, 17, 18, and 19. The western portion of this area is drained by the White Woman and its tributaries which flow into the Modoc basin. Beaver creek or Ladder creek, which is the tributary of the Smoky Hill river, bends southward, crossing into town 17 for a portion of its course. Along the northern border of the area a number of short cañons which are tributary to the Smoky Hill river cut into this area. The southern border of the area has no distinct drainage system. In the southeast corner of Scott county there is a small lake which receives its drainage water from a few short draws. The headwaters of the Pawnee Fork take their rise in the southeast portion of this area, extending into the southern portion of Lane county. The general topography of the country is a gently undulating plain. The streams have usually a narrow valley with gently sloping banks. The tributaries of the Smoky Hill river have deep, rugged cañons and where the streams pass over the eastern border of the area, descending from the Tertiary over the Niobrara, the valleys are deep and have strong bluff lines.

The geology of this area is very simple. The surface formation is the Tertiary, which extends in even and comparatively thin sheets over the whole country. The eastern border is very irregular, as is shown by the mapping, and along the Smoky Hill river are numerous deep cañons. The underlying floor to the Tertiary is the Niobrara. This formation, which is seen bordering the Tertiary along the Smoky Hill and extending in an irregular band from the northeast to the southwest along the eastern limits of the Tertiary, extends westward underneath the surface formation, evidences of its presence being nearly everywhere obtainable from reports of wells and occasional exposures on the surface. Following westward along the branches of the Walnut, we find it outcropping on lower and lower ground along the banks of these streams. Its most westward exposure is just southeast of Dighton, where it appears in the bed of the south fork of the Walnut. It occasionally comes to the surface further west, as at the western side of Alkali lake, in the southeastern portion of Scott county; on the White Woman, south of Coronado; and at the state line where the White Woman enters Greeley county at the place known as the Wild Horse Corral. These areas are shown on the map.

The Niobrara floor is comparatively regular. It, however, has, as is shown from a careful study of the localities in which it appears to the surface or is found in the wells, many irregularities, probably having in general the configuration of a gently undulating plain with occasionally bluff lines formed by pre-Tertiary erosion. Southeast of Scott City, a short distance east of the Modoc basin, wells reach the Niobrara at a depth of twenty or thirty feet. The Niobrara is not exposed in the immediate vicinity, the nearest place at which it is found being at Alkali lake. East of this locality, and north of it also, the wells reach a depth of from 90 to 100 feet before obtaining sheet water, and most of them do

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not encounter the Niobrara at all. Modoc basin, which is a great depression in the plain's area, receiving the flood waters of the White Woman, is usually dry. Many farms are located around it. This depression is much lower than the area east of it, where the Niobrara comes within twenty or thirty feet of the surface. The wells dug around the basin do not reach the Niobrara, and some of them are 80 feet deep. It would thus seem that there is a rise in the Niobrara floor extending in a north and south direction from the eastern border of Modoc basin to the exposures of Alkali lake. This may be due to Tertiary erosion or, possibly, to a faulting of the formation. Along the valley of the White Woman wells occasionally reach the Niobrara, especially in the vicinity of the exposure south of Coronado. Further west, in Greeley county, there is apparently a sub-Tertiary ridge of the Niobrara which comes to the surface at the state line where the exposure is mapped. In the western portion of Greeley county, wells which extend through the Tertiary encounter the Niobrara over a large area, the eastern limits of which are approximately at Horace. This area widens to the west, forming a triangular shaped area.

Along Ladder creek there are no exposures of Niobrara, except near its confluence with the Smoky Hill. The bends to the south in this creek where it enters township 17 have banks of Tertiary with exposures of rough sandstone which belong to the mortar beds. The deep wells in the vicinity of the stream are from 80 to 90 feet deep and do not reach the Niobrara. Along the Missouri Pacific railroad, from Pen Dennis to Utica, Ransom and Brownell there is an eastern extension of the Tertiary, shown on the map, which is the level upland between the headwaters of the streams which flow into the Walnut to the south and the short cañon which flows into the Smoky Hill river. Near the borders of this area the Tertiary is comparatively thin, but in the central portion of it the wells are from 65 to 85 feet deep, extending into the sheet water of the underflow, the exact thickness of the Tertiary not being determinable since the wells are dug no deeper than is required to obtain an abundant supply of water. There is practically no bottom land along the streams of the Tertiary area, but the immediate valley of the streams is filled in with sand and gravel, and in these deposits water can be be obtained at a very shallow depth, except in very dry times. Often places can be found where two spade lengths will reach water in the sands, especially along White Woman creek. The smaller draws are not so abundantly supplied with this concealed flow of water.

The water which is obtained from wells over this area is almost wholly the sheet water or underflow supply of western Kansas. The depth at which it is obtained varies considerable. The average depth of shallow wells and those along the valleys of the streams is from 30 to 50 feet. The average depth of the deep wells, about 80 to 90 feet, the depth in all cases being relative to the level of the upper surface of the sheet water. The question as to whether the sheet water is at a constant level or not over the entire area, or as to whether it has a slight eastward flow, cannot be determined from the depth at which it is reached until a careful topographic survey of the country is made.

The fact that the underflow water is not everywhere obtainable, even by digging entirely through the Tertiary, is evidence of the unevenness of the sub-Tertiary floor, and that there may be a division of the underground sheet of water into a number of areas and having an eastern flow accommodating itself to the irregularities and elevations on the Niobrara sub-Tertiary floor.

Around the borders of the Tertiary area there are numerous springs, some of which have a steady flow. These come from the base of the Tertiary and indicate the level of the sheet water. Such localities are found along the Hackberry

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and Spring creek which are tributaries to the Pawnee, the various forks of the Walnut and their tributaries, the head waters of Big Timber Creek, and in the heads of the short cañons and large draws which flow into the Smoky Hill river. The leakage from the seep water, or underflow, into these streams is, as a usual thing, disguised by a surface covering of sand and gravel, through the base of which the water finds its way into the channels of the streams and the underflow in the sands and gravels of the stream beds. As we ascend the streams, more particularly the larger ones, when we approach the horizon of spring water, we find the Niobrara giving away to the Tertiary as we reach high valleys.

In the streams below the locality of the springs there is frequently a constant, although limited, flow of water observable even in dry periods, especially where the Niobrara forms the bed of the stream and the deposits of sand and gravel in the bed are not sufficient to carry the water below the surface. Occasionally water is obtained over the Tertiary area in the Niobrara. It, however, is not an abundant source and the localities in which the wells depend upon it are near the border of the Tertiary, or at places where the Tertiary outcrops at the surface, or is met with at very shallow depths. The character of the Niobrara is such that it carries very little water and, being practically impervious, forms a floor for the sheet water. The yellow, chalky shales which constitute a portion of the Niobrara formation are, however, capable of absorbing quite a quantity of water. Where the irregularities in the surface of the Niobrara are found, wells occasionally reach the yellow, chalky shales before they have been dug to the level of the sheet water in surrounding areas. These shales being capable of absorbing and holding a small amount of water will be found to contain a supply of water probably from the sheet water, and consequently wells which are described in popular language as having obtained their supply of water from yellow soapstone belong to this class.

In the western portion of Greeley county, where the Niobrara forms an underground ridge, water is very difficult to find in abundance, and often where a well is supplied with even a small quantity, the character of the water is such that it is not very usable because of the mineral substances contained in it. It would seem that the Niobrara floor under this area rises so decidedly that the underflow of sheet water does not find its way over it, and in consequence the Tertiary formation, although being in general of the same character as in other places, does not contain a supply of water. Along the valley of the White Woman, however, there is a supply of water in the sands, gravels, and clays, which seemingly is brought by the drainage of the valley.

The question of obtaining artesian water, which would be expected to be found in the Dakota formation, by drilling very deep wells, is one which cannot be very fully discussed. Over this vast area there are no records of deep wells which show what thickness of the Niobrara formation is expected along the eastern border where it is very thin, due to pre-Tertiary erosion. It will be remembered that below the Niobrara is found the Benton formation, which does not contain a supply of usable water. If a deep well were dug in this western portion of this Tertiary area, it would probably pass through, first, the Tertiary, then the Niobrara and then the Benton before reaching the Dakota. As no such wells have been dug, the thickness of these formations can only be estimated over this area from a knowledge of their average thickness where they are exposed individually. The section along the western state line shows the probable relation of the surface to the underlying Dakota. No topographical survey or line of levels having been made, the section, of course, is only approximated. The artesian well at Coolidge is a flowing well, but it will be observed that it occupies a position on the

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base of the section, and if the same water were reached by a well in Greeley county, it would come far short of rising to the surface. At Sheridan Lake, in eastern Colorado, a deep well was sunk to a depth of 1,300 feet and was reported not to have passed through the shales of the formations above the Dakota. It contained a small supply of water which was mineral in character inasmuch as it probably came from the shales.

The Oakley Area.—Under this head is described the water supply of the country around Oakley. The area, studied in particular, embraces the northwest corner of Gove county, the northeastern corner of Logan county, the southern portion of Thomas and the southwestern portion of Sheridan county. It embraces towns 10, 11 and 12, between ranges 29 and 35, inclusive. It is approximately the divide between the south fork of the Solomon river and the Smoky Hill river. The upper portion of the Saline river flows in its northern portion from west to east, and in its southern portion are the various branches of the Hackberry creek and also some smaller tributaries of the Smoky Hill. The country is approximately a level plain. The valleys of the streams, excepting the Saline, near the eastern portion of the area, are relatively unimportant. None of the streams flow except in rainy seasons. Along the southwestern portion of the area there is a decided line of bluffs which extend approximately parallel to the Smoky Hill river. They are nowhere abrupt, and are situated from four to six miles north of the stream. From there the slope is gradual down to the bottom lands. The level plains around Oakley are a portion of the Tertiary area of western Kansas, and the bluff line along the Smoky Hill river is the border of that formation where the river valley has cut through it down to the Niobrara. In the vicinity of Gove the Niobrara is also exposed along the Hackberry; but here there is not so decided a valley, and consequently no bluff line, as at Russell Springs.

The Tertiary formation which lies above the Niobrara, and extending to the north forms the level prairies and consists of clay and sand, is a formation in which the wells find the sheet water at an average depth of about 100 fest.

The water supply of the Oakley area is principally the sheet water found in the base of the Tertiary. There is, however, along the branches of the Hackberry, in the vicinity of Gove City and in the Smoky Hill valley, southwest of the Oakley area, a considerable deposit of sand and clay mixed with gravel which is Tertiary in its origin and carries an underflow of water which is a source of supply to shallow wells. The underflow along the Hackberry southeast of Gove City is very important, and its presence makes possible the raising of alfalfa on the bottom lands which have a natural sub-irrigation. At Gove City the average depth of wells in the southern part of the town is about 40 feet and the water which is obtained in them is of this character. The wells in the northern part of the town often strike the Niobrara without finding water, the covering of Fluviatile material not being sufficient to carry an underflow or lying so irregular that the underflow is drained away from the locality at which the well is sunken. Near the heads of the streams which drain the Oakley area, where the valley is eroded entirely in the Tertiary, there is practically no underflow in the Fluviatile deposits, since they are so very limited and have no impervious substratum to prevent its sinking into the Tertiary. The underflow in the Fluviatile deposits is practically confined to areas where the Niobrara is found outcropping or has only a thin covering of worked over Tertiary material.

Along the Saline river, beginning near the western margin of this area, the wells dug in the valley of the stream evidently reach the same level in order to

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obtain the sheet water that they do on the upland. As we follow down the stream, the valley deepens and the depth of the wells in the valley decreases, so that at section 36, town 10, range 32, the well dug by Mr. Anderson finds an abundant supply at 36 feet, this being probably the same in character as that at the state well, located a few miles southwest, at Oakley, in which the sheet water was first struck at about 100 feet. In the Saline, north of Grainfield, the bottom of the valley is eroded nearly down to the sheet water, as is shown by the presence of bogs and ponds. Along the Saline, east of the Oakley area, as here described in particular, the Niobrara, which is the floor on which the sheet water rests, is exposed in the southeast of section 22, town 10, range 27, northeast of Buffalo Park. At this place the Saline flows a constant stream of water, which undoubtedly has its source in the sheet water from the Tertiary.

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Pumping Tests.

By O. P. HOOD.

A portion of the work laid out by the Board was the testing of various forms of pumps to ascertain their efficiency and general desirability for the labor expected of them. How best to do this was a matter to which the Board gave considerable thought. Separate tests and trials of each pump at the respective stations would involve a large expense, much inconvenience and probably prove unsatisfactory--one test being with difficulty compared with another on account of dissimilarity of conditions. Finally, Commissioners Tomblin and Sutton visiting the State Agricultural College to arrange for a lease to it of the Logan station, No. 5, in the spring of 1896, saw there in place machinery and appliances suitable for the work the Board desired to do, and suggested that the pump tests be carried on at that place under the charge of Prof. O. P. Hood. Arrangements were then and there concluded by which Professor Hood took charge of the pump tests for the Board. The Board furnished him with such machines and appliances as the college did not possess and were necessary to carry on the work, and the professor performed the experiments and made the report given below without compensation. Under this arrangement, the Board purchased an hydraulic transmission dynamometer, made to order and costing $237, which was supplemented by an ingenious device designed and constructed by Professor Hood, and called a reciprocating dynamometer, and the Agricultural College furnished the other necessary machinery. Owing to delay in receipt of the instruments ordered, the work could not be commenced until the middle of September.

Professor Hood's experiments are in a new line, and will prove of very great value. The main expense having already been incurred, and the machinery and instruments on hand, it is to be hoped that the legislature will make the necessary appropriation for pursuing these investigations further. Professor Hood's report to the Board is here given in full:

To the State Board of Irrigation:

Gentlemen--I have the honor to make the following report of the pump tests undertaken at the direction of the Board.

What is the efficiency of the reciprocating pumps used in conection with

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windmills for raising water? The following paper and record of tests is submitted as a partial answer to this question.

It is proper to first inquire whether the absolute efficiency is a matter of sufficient importance to warrant careful measurement. By efficiency of a pump is meant that per cent. of that power which is delivered to the mechanism which is usefully returned by water lifted. So long as there are other resistances to overcome than that of simply lifting the water, the efficiency must be something less than 100 per cent. An English reference states that previous to 1851 no pump had been made whose efficiency was above 40 per cent.; that is, the remaining 60 per cent. of the power applied was wasted in overcoming other resistances than that of the desired lifting of water. The mechanical efficiency of a device, while important, is frequently of much less importance than other qualities, such as reliability of action, simplicity, ease and low cost of repairs, and reasonable first cost. If the cost of power is high, some of these desirable qualities may be sacrificed for increased efficiency, while with a low cost for power such a sacrifice would not be justified. With windmill irrigation, however, another factor makes the efficiency of importance. Successful irrigation demands an absolutely reliable water-supply. If to an unreliable rainfall we add an unreliable supply of mechanically raised water, we have not succeeded.

While some months of the year furnish ample wind power, the hot summer months furnish an amount much below the average. It is in this season, when there is the greatest need of raising water, when the average winds are low, and the periods of rest of the windmill may be long, that it is of importance that what power is furnished by a mill be used to the greatest advantage.

If the more efficient device can be obtained without sacrificing other necessary qualities, it should be discovered and given preference. In the case of the reciprocating pump, the efficiency depends so largely on proportion of parts, design of valves, and piston speed, that considerable variation can be found in pumps of equal simplicity. It can be answered, therefore, that the mechanical efficiency of the pump is a matter of importance to irrigators. I have been unable to find published data available on this subject. Experiments and conclusions relative to steam-driven reciprocating pumps are obtainable and are of service to designers. The small bucket pump has not heretofore been required in a position where the efficiency was of sufficient importance to warrant published experiments.

To find the efficiency of a pump, it is necessary to know what force has been supplied to the pump, and the space through which it acts.

It is also necessary to know how many pounds of water have been lifted, and the vertical height from the surface of the water in the well to the lip of the discharge opening. The following is a description of a plant erected by the mechanical department at the Kansas State Agricultural College for measuring these quantities. A rectangular pit 12x15 feet, walled and cemented, was available for a well. Forty feet above this a floor was placed carrying a line shaft driven by an engine. A Flather transmission hydraulic dynamometer acted as a counter-shaft between the line shaft and a vertically reciprocating crosshead carrying the pump rod. The dynamometer shaft carried a pinion which drove a gear carrying an adjustable crank-pin. The crank-pin drove the crosshead by a connecting rod. The power transmitted through this dynamometer was recorded on a traveling card by a pencil whose position depended on the force transmitted by the belt. This

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made a permanent record possible of all the power furnished to the device by the belt. It was believed to be desirable to check the results of this machine by a reciprocating dynamometer placed directly in the pump-rod. For this, a new device was designed. As a part of the pump-rod, a movable piston was placed, so connected that when the rod was in tension the piston was forced into its containing cylinder. In the cylinder, oil was placed. Oil being practically incompressible, the piston would not move when the rod was subject to tension unless an outlet was provided for the compressed oil. The oil would be under a pressure corresponding to the tension of the rod. The oil was allowed to exert its pressure upon the piston of a Crosby steam-engine indicator, the movement of whose small piston was opposed by a spring of known resistance. The area of the dynamometer piston was five square inches; that of the indicator, one-half a square inch. The maximum movement of the dynamometer piston was .04 of an inch, which represents the lost motion in the pump-rod. To enable this device to measure compression as well as tension in the pump-rod, it was necessary to supply an initial compression on the oil by means of a spring forcing the piston into the cylinder. The spring furnished an initial compression on the oil and the corresponding position of the indicator pencil represented zero stress on the pump-rod. Any tension in the rod was recorded by the raising of the pencil due to the greater compression of the oil, while any compression in the rod was recorded by a lowering of the pencil due to a reduction of the initial compression of the oil caused by the spring. The indicator drum carrying the record paper was given a reduced motion corresponding to the pump-rod. The record drawn by the indicator gave the stresses in the pump-rod at each part of the stroke and with no device using power between it and the pump. The record furnished by the Flather dynamometer gave the power necessary to run the machine itself, the two gears, crank-pin, connecting rod, and crosshead, together with the pump. The record was retraced with the machine running at the same speed, but with the pump-rod removed. The difference between the two diagrams gave the work required to drive the pump and the friction of the machine due to the extra load of the pump. The record of this machine was therefore always higher than that from the more direct dynamometer in the pump-rod by the amount of work necessary to overcome the friction due to the load of the pump. For this reason, all computations are from diagrams taken by the reciprocating dynamometer, the other being used as a check on any possible misbehavior of the device in the pump-rod.

Figure 1 shows a card taken from a 6-inch cylinder, 14-inch stroke, making 10 strokes per minute. The distance, A B, represents the stroke of the pump, 14 inches. The tension on the pump-rod as it starts on the up stroke is shown by a C. The distance of C D above the line a b shows the continued tension in the rod due to accelerating and lifting the column of water on the up stroke. At the beginning of the down stroke D B is drawn, and B A during the completion of the down stroke. These lines all being above a b, shows the rod to be always in tension at this speed. From the area a C D b, the average height of the line C D can be obtained. This height, multiplied by the tension of the indicator spring, corresponding to one inch of vertical pencil movement, gives the average compression per square inch in the oil cylinder. This, multiplied by the area of the cylinder, gives the average tension of the pump-rod. This average tension, acting through the length of stroke of the pump, gives the foot pounds of work delivered to the rod on the up stroke. The rod being in tension on the down stroke, tends to act as

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a motor, and the work of the down stroke similarly found from the area a A B b must be taken from the work of the up stroke to find the actual work expended on the pump-rod for one up-and-down stroke. The maximum and minimum stress on the rod is shown by the diagrams and given in the tables. The instrument has proved sensitive to variations of stress in the pump-rod, showing the opening and closing of valves and fluctuations of stress due to impact of water, spring of pump-rod, etc.

The pumps were suspended in the open well, usually in a position where the lower valve was a few inches below the water level. Up to a lift of 40 feet, the conditions were exactly those of the usual open well. Pumps were tried at various lifts and various speeds until either the valves showed a failure to work or the initial stress on the up stroke seemed liable to break some of the machinery. The pumps so far tested were furnished by the builders or their agents. The following were asked to submit pumps for test: Mr. H. B. VanVoorhis, Topeka, Kas.; Crane Company, Kansas City, Mo.; U. S. Water and Steam Supply Company, Kansas City, Mo.; Fairbanks, Morse & Co., Kansas City, Mo.; National Pump Company, Kansas City, Mo.; Mr. J. W. Aiton, Kingman, Kas.; English Supply Company, Kansas City, Mo.; Aermotor Company, Kansas City and Chicago; agent Stover Windmill Company, Kansas City.

All agreed to loan pumps for test except the last three firms. Only the first three sent pumps, as follows: Mr. H. B. VanVoorhis, of Topeka, an 8-inch cylinder, 10-inch stroke, of his own invention and built at the Topeka foundry. The U. S. Water and Steam Supply Company, a 4-inch common pump cylinder, an 8-inch irrigation cylinder and a 3-inch deep-well cylinder. Crane Company furnished 6-inch, 5-inch, 4-inch and 3-inch cylinders of the Frizell pattern. The method of test of all pumps was as follows: The pump was set with the desired height of discharge pipe. The pump was run at the desired speed, 10 strokes per minute being the lowest obtainable, and varying by five up to the possible limit. At each rate of speed, two cards from the reciprocating dynamometer were taken. To establish the zero line on the cards, the line was drawn by the indicator pencil with the pump-rod disconnected from the crosshead. After a series of cards had been taken, the pump was again run at each of the various speeds, and the water lifted during 20, 30 or 50 strokes delivered into a tank supported on a scale platform, and weighed. Two or more measurements of discharge at each speed were taken. The discharges at each height of lift were plotted on rectangularly ruled paper, discharges as ordinates and speeds as abscissas. A smooth curve was drawn through these points eliminating the minor variations. Where these curves from various lifts coincided within a small per cent., the readings of the various curves were averaged at each speed, and a new curve plotted, which was taken to represent the true discharge at each speed. So far as tested, there seems to be no regular variation in discharge depending on the height of lift, but a variation due to speed is plainly shown.

The first pump tested was an 8-inch pump of uncommon design by Mr. VanVoorhis, of Topeka. As shown by the accompanying drawing, Fig. 2, the pump consists of a cylinder of wrought pipe, the lower end being closed by a large leather clack valve. The lower valve-seat opening is 34¼ square inches, and 70 per cent. of the plunger area. Instead of the usual piston, a hollow plunger, turned on the outside, is used. The upper end of the plunger carries a leather clack valve covering a valve opening of 46.4 square inches, or 94 per cent. of the plunger area. The lower valve weighs .17 pounds per

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square inch of valve seat opening, and the upper one .21 pounds. The plunger is packed on the outside by a packing leather secured to the top flange of the cylinder. The pump-rod is connected by a bale to the plunger, allowing the upper valve unobstructed movement within the bale. The accompanying tables, I and II, give the results of tests. To more clearly present this, Fig. 3 shows the same data arranged graphically:

In the plotted line, each small mark shows one measurement. The discharge curve shows a great reduction in the amount of water delivered as the speed increases. This is due to the design of the valves. From the table, it will be seen that at 85 strokes per minute (a very high speed) 21 per cent. of the up stroke has finished before the upper valve has been able to close. During most of this time, water is slipping back through the two open valves. At this point, the ascending plunger is moving more rapidly than at the beginning of the stroke, and in meeting the downward flowing column of water a great stress is brought on the pump-rod, in this case 1,500 pounds, or over six times the average pull. On the down stroke, the lower valve fails to close until 37 per cent. of the stroke has finished. The late closing of this form of valve at high speed is inseparable from its design. While it promises the largest valve-seat opening, other difficulties are met. A clack valve hinged at one side of a circular-valve opening must raise at its outer point somewhat higher than the radius of the opening to have a discharge area about its circumference equal to the circular valve-seat opening. This means a comparatively high lift and a corresponding long time to close. Opening into a pipe, the most restricted space may be the annular space between the edge of the valve and the wall of the pipe. The opening of the valve seat therefore may not be the true unobstructed valve opening. To make a quick closure and avoid slip of the water, the valve must have a low lift and be heavy. To work easy and obstruct the water as little as possible, the valve must be light and open wide. These two requirements are directly opposed to each other, and any design must be a compromise between these two extremes. It will be noted that this pump was tested at higher speeds than any of the others. While the hammering of the valves did not appear serious, the jerk on the pump-rod became serious, and limited the practicable speed. Within the usual range of windmill speeds, the pump is more efficient than others tested at the low lift used. The efficiency remains above 50 per cent. up to a piston speed of about 80 feet per minute, and could be increased on a longer stroke. This is an excellent record on so low a lift. Its simplicity, ease of repair and cheapness of construction recommend it. One reason why it can be run at rather higher speeds than usual is its rapidly falling discharge rate, requiring less useful work to be done per stroke. Another reason is the small resistance on the down stroke. The outside packing of the plunger is under slightly greater pressure on the inside on the down stroke, which relieves the leather from the plunger and greatly reduces friction. Figs. 4 and 5 show stress cards at 20 and 85 strokes per minute.

The point A shows the closing of the upper valve. Point B is made at the lower valve closure. Such part of the diagram of Fig. 5 as is below the zero line shows compression in the rod. Experiments with the pump at other heights of lift have not been completed.

Total weight of pump, 146 pounds. Weight of plunger, pump-rod, etc., 101.5 pounds. Pump-rod of 1-inch pipe.

Crane Company, of Kansas City, furnished cylinders known as the Frizell pump, in sizes of 3-inch, 4-inch, 5-inch, and 6-inch. The 4-inch and 6-inch

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sizes have so far been tested. The design of sizes below 6-inch is shown in Fig. 6.

The cylinder consists of a wrought-iron brass-lined tube. The suction valve is contained in a valve chamber screwed to the lower end of the cylinder. The valve chamber contains a heavy disk valve guided by radial partitions extending from the surrounding enlarged valve chamber. The disk is slightly smaller than the cylinder, allowing easy removal by hooking into the bale shown on the top of the valve. The piston carries a butterfly valve. The dimensions of the 4-inch size are as follows:

Cylinder diameter, 3.73 inches; valve-seat area in piston, 4.29 square inches; effective area when butterfly valves are wide open, 3 square inches, or 27.4 per cent. of cylinder area; lower valve-seat area, 5¼ to 6.2, depending on lift of valve; area of valve chamber openings per inch of valve lift, 9.85 inches; pump-rod, ½-inch pipe; weight of pump bucket, rod, etc., 39½ pounds; weight of pump, 57½ pounds.

This pump was set without any suction length, the surface of the water being slightly above the lower valve seat. The record of tests at six different lifts and speeds, from 10 to 55 per minute, is shown by tables III and IV, and graphically in Fig. 7.

The efficiency of this pump is quite constant at each speed tried, but increased with the height of lift. It is to be expected that with increased lift the proportion which the friction of the pump bears to the total work performed will decrease, thereby increasing the efficiency. To what extent this increase can be expected to continue is indicated in Fig. 8.

The range of efficiency at each lift is plotted, and the curve joining these shows that no considerable increase in efficiency can be expected at higher lifts. The speed of this pump is limited by the action of the lower valve. At a piston speed of about 180 feet per minute, or about 50 strokes, the lower valve was raised above the valve chamber into the cylinder. Having left its seat so far, it frequently would not return until half the down stroke had been completed. When seating at this high velocity, a serious pounding was produced. The discharge of this pump shows a slight increase per stroke up to a speed of 40 strokes, then a gradual decrease until serious pounding reduces the discharge an uncertain amount. This pump was used with a 4-inch discharge pipe. To test the effect of using this pump as a force pump, and also to test under higher pressures than the direct lift of 40 feet would furnish, the pump-rod was furnished with a turned portion fifty-five sixty-fourths of an inch in diameter, adapted to play in a stuffing box. The discharge pipe was capped with a tee, turning the water column horizontally. With a short pipe and ell, the column was brought upright and completed to a height comparable with one of the previous tests. A stuffing box added to the tee for the pump-rod was packed so lightly as to allow a small leakage. Table V shows the results. The efficiency was reduced nearly a third at this lift owing to the stuffing box and two turns in the water column. To test under higher pressures, the discharge pipe was furnished with a connection to a large air chamber carrying a pressure gage, and the flow of water was restricted at the discharge height by a disk valve controlled by hand. The flow being restricted, a pressure of air in the air chamber was produced, simulating an hydraulic column corresponding in height to the pressure shown by the gage. By regulating the discharge, a very uniform pressure could be maintained. In this way, tests at pressures corresponding to 47.37 feet and 70.5 feet were made with results shown in table VI. If allowance is made for the

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foot pounds of work absorbed by the stuffing box and elbows, the efficiencies will be increased about 15 per cent., raising them to about the efficiency shown at the 30-foot lift.

The 6-inch pump of this make, shown in Fig. 9, while retaining the same style of suction valve and chamber, discards the valves in the piston. These are replaced by a series of small clack valves surrounding the cylinder and opening upward into an annular chamber inclosing the pump cylinder. Water drawn in through the suction valve is forced through the eight upper valves, on the down stroke of the piston, up into the surrounding chamber, and follows the piston on its downward motion. On the next up stroke, this water is lifted. The pump is remarkable for its high efficiency and for its sustained efficiency at higher speeds. So far as tested, the speed was limited only by the ability of the connections to stand the jar incident to the closing of the upper valves. At some higher speed, no doubt the lower valve would be drawn into the pump cylinder, as in the 4-inch size, and produce serious pounding. Fig. 1 and Fig. 10 show stress diagrams from this pump at a lift of 22.66 feet, and at speeds of 10 and 55 per minute. Fig. 11 shows the experiments plotted and the efficiency lines. Tables VII and VIII show the same data with the maximum and minimum stress on the rod. When the minimum stress is negative, it shows compression in the rod. The efficiency falls about 5 per cent. as the speed increases from 10 to 50 strokes. Fig. 12 shows the increase of efficiency with the lift. But little further increase can be expected at higher lifts. This curve would finally reach a maximum, and then fall on account of increased friction in the pump. The discharge increases slightly up to 20 strokes, and falls thereafter. The pump had a 6-inch spiral riveted discharge pipe. The lower valve-seat opening varies from 2.66 inches to 15.36 square inches, or 59½ per cent. of the cylinder area, depending on the lift of the conical part of the valve. The weight of the valve is about one pound per square inch of valve area. The cylinder diameter is 5.74 inches. The upper valve-seat area of eight small valves is 29.69 square inches, or 3.82 inches more than the cylinder area. The weight of the pump-rod, piston, etc., is 62 pounds; of the pump without rod, 270 pounds.

The U. S. Water and Steam Supply Company, of Kansas City, sent two cylinders made by the Mark Manufacturing Company, of Chicago. The pumps are very well made in every detail. The 4-inch pump, Fig. 13, is fitted for a 2-inch discharge pipe.

The upper valve carried in the piston is a metal disk-valve of fixed lift. The valve-seat opening is 3.73 square inches, or 30 per cent. of the piston area. The lower valve is a metal wing-valve seating on a rubber ring. The valve opening is 2.26 square inches in the clear, with the greatest lift of valve of .54 inch. This is 18 per cent. of the piston area. Owing to the relatively small discharge pipe, and consequent high velocity of water, the discharges for this pump increase beyond the piston displaced volume at speeds above 25 per minute at the lift of 25 feet. Beyond 40 strokes, the increase is quite marked, as shown in Fig. 14. The efficiency is shown in Fig. 15 as well as in the accompanying tables, IX and X. The stress card shown in Fig. 16 indicates the late closing of the lower valve, due to the upward current of water continuing after the piston has started on the down stroke. The pump-rod, bucket, etc., weighed 37 pounds. The efficiency curve would fall less rapidly as the speed increases if supplied with a 4-inch discharge pipe. This would

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make but little difference at the low speeds, but at the higher speeds is of importance to high efficiency.

The 8-inch pump of this make, Fig. 17, gave the highest efficiency at slow speed of those tested, reaching above 85 per cent. The pump consists of a brass cylinder with brass disk valves and brass valve seats. The lower valve is leather-faced and limited in its lift by a cross attached to a pendant spindle on the valve, the cross striking the under side of the valve seat at its limit of movement. The upper valve slides on a central spindle having a shoulder which limits the valve lift. The cylinder diameter is 8 inches. Lower valve-seat area when obstructed by the cross, 18 square inches, or 36 per cent. of the piston area. Maximum lift, one and three-sixteenths inches. The area between the edge of the disk and the cylinder walls is 53 per cent. of the cylinder area. The upper valve-seat area is 17.36 square inches, or 34.7 per cent. of the cylinder area. The lift of each valve is such as to make the circumferential discharge area slightly in excess of the valve-seat area. The discharge pipe was 6-inch. As the velocity of discharge water was never high, an 8-inch discharge pipe would very slightly increase the efficiencies at the higher speeds. The pump is thoroughly well made in all respects, and very durable. The tests as shown in the tables, XI and XII and in Fig. 18, show a very high efficiency at piston speeds below 50 feet per minute, and falling to about 60 per cent. at piston speeds of 100 feet per minute. Fig. 19 shows a stress diagram at a speed of 30 strokes per minute. The closure of the upper valve is early and of the lower valve a little later in its stroke.

The weight of the complete pump is 145½ pounds; the weight of piston and pump-rod used was 67½ pounds; the pump-rod was ¾-inch pipe; the lower valve weighs .27 pounds per square inch of valve-seat opening.

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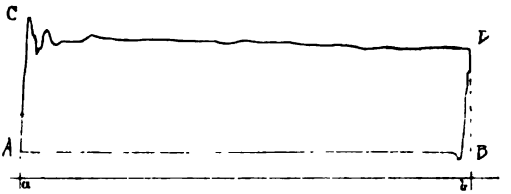
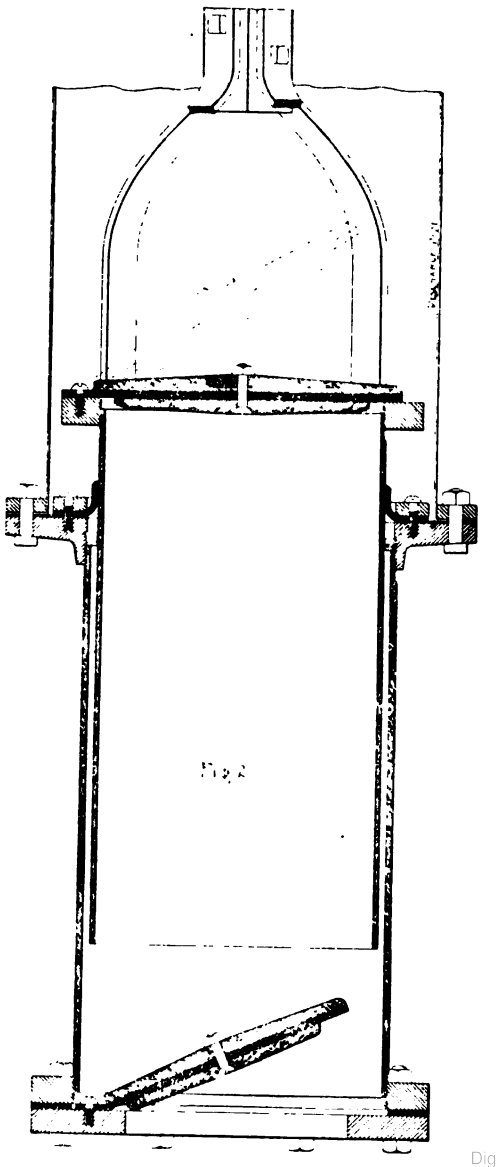


Fig. 1.



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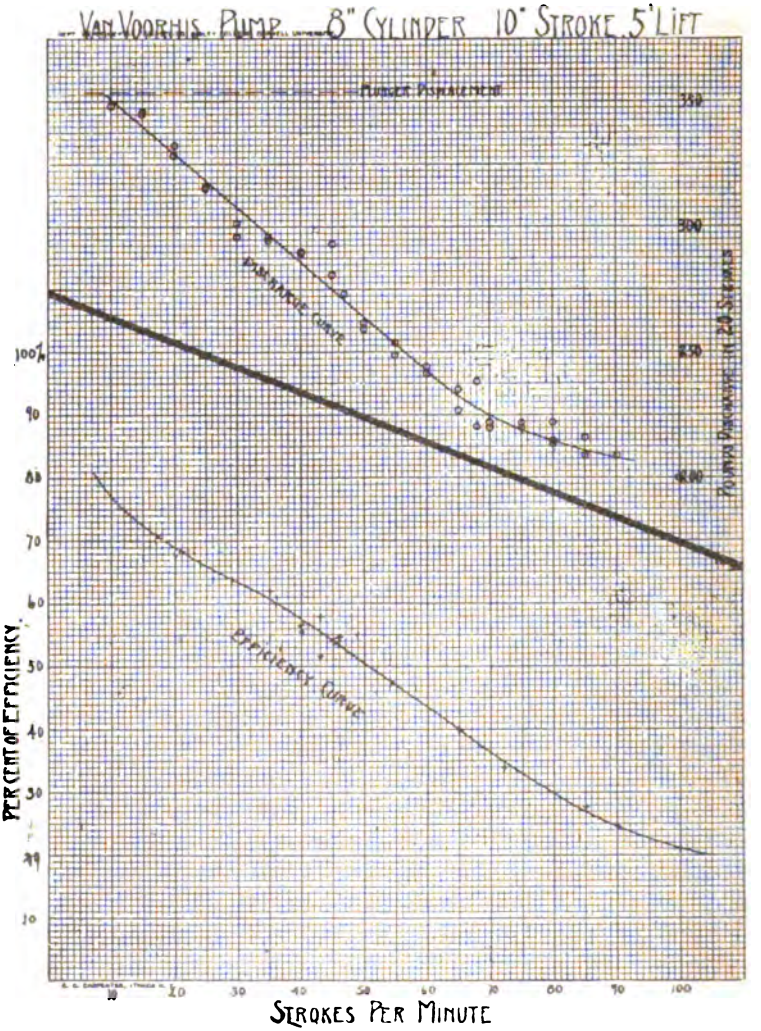

Fig. 3.

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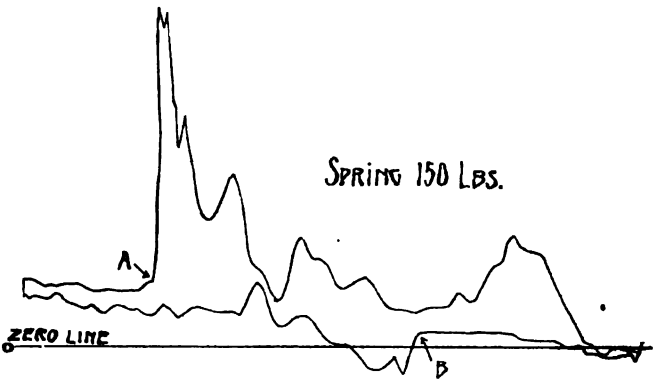


Fig. 5.

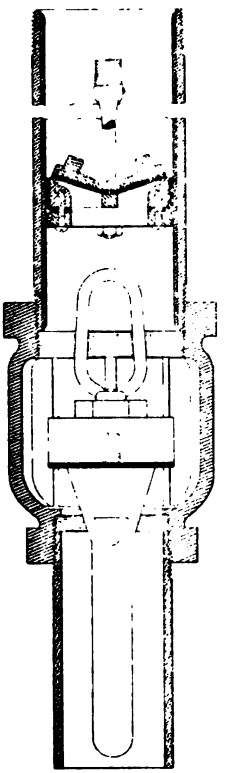
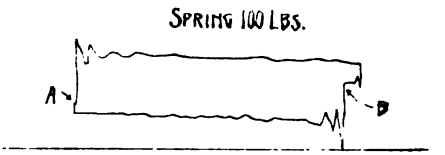


Fig. 6.



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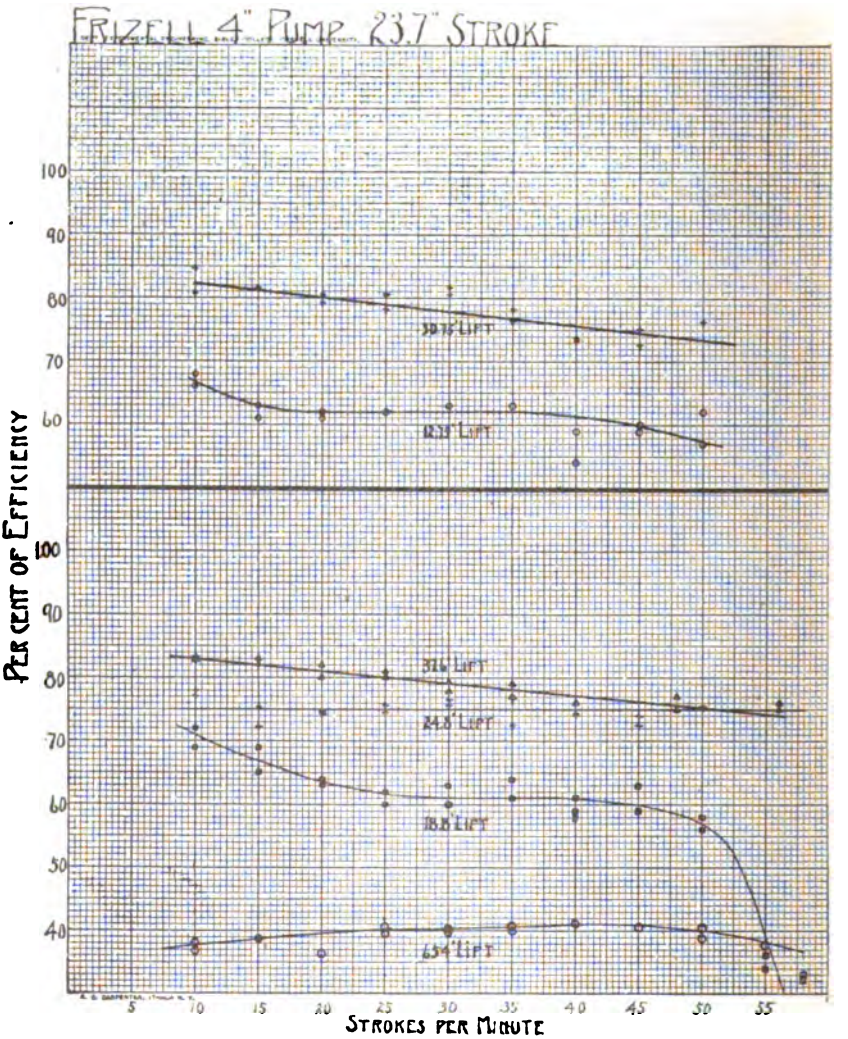

Fig. 7.

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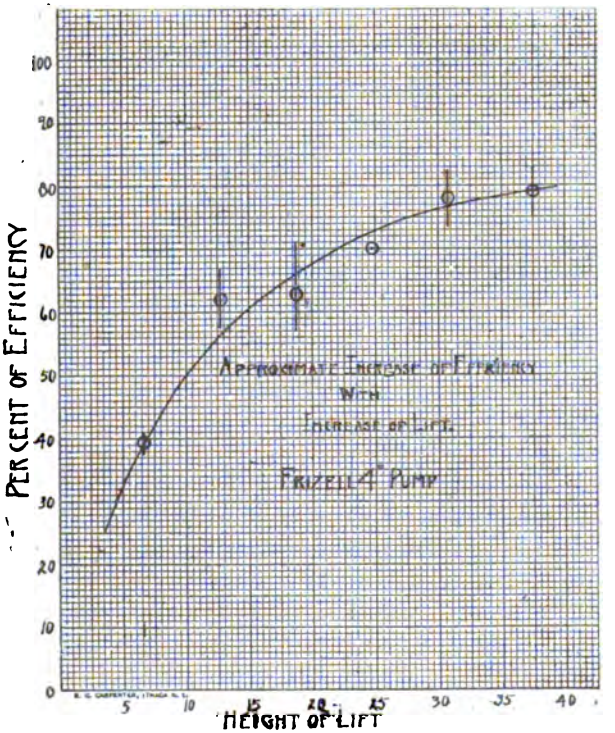

Fig. 8.

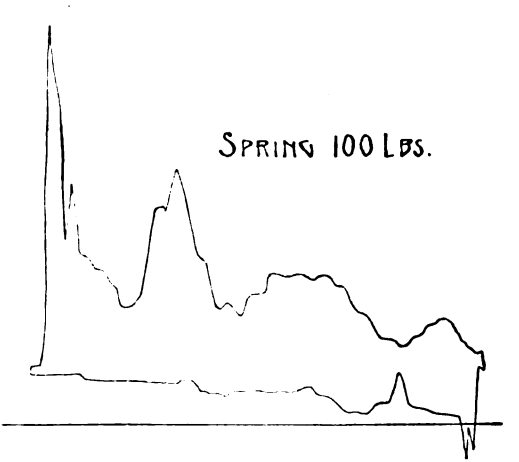

Fig. 10.

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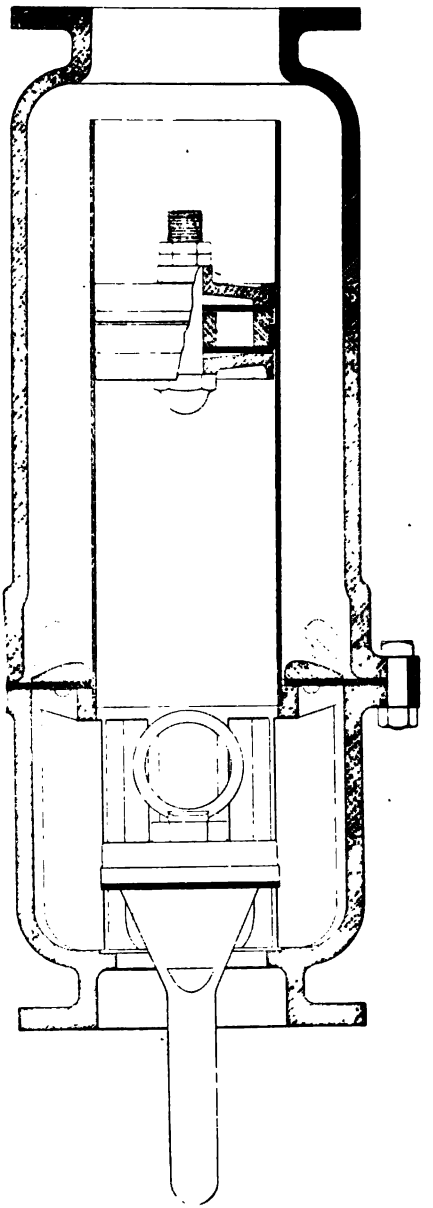

Fig. 9.

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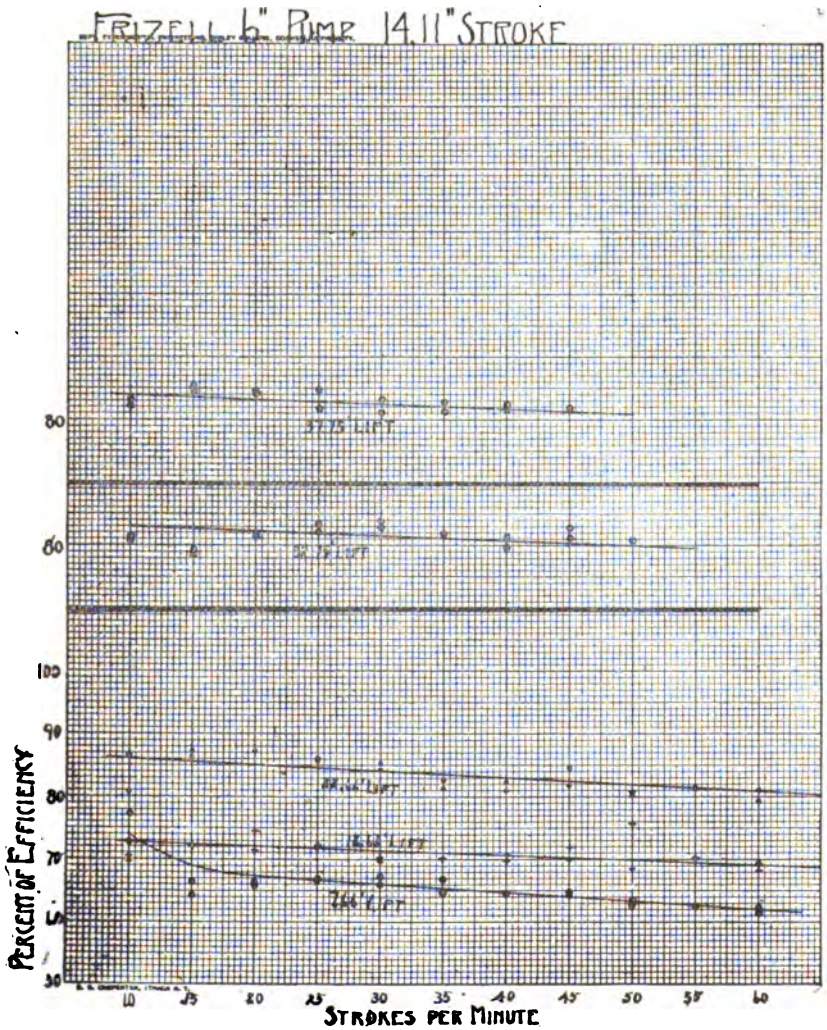

Fig. 11.

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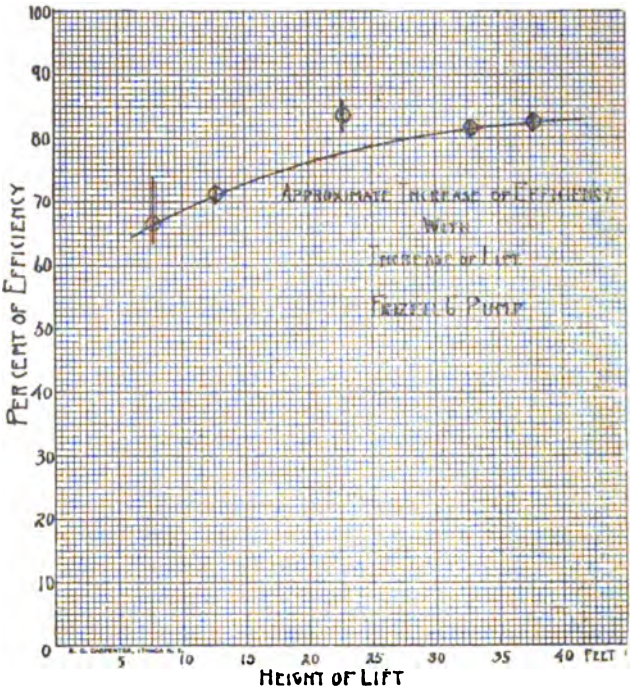

Fig. 12.

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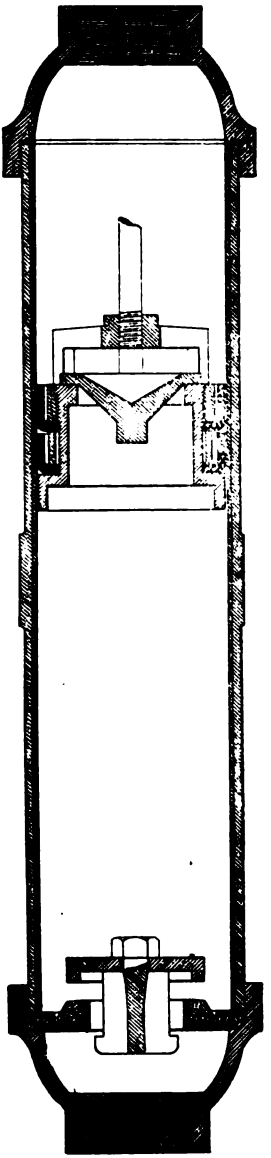

Fig. 13.

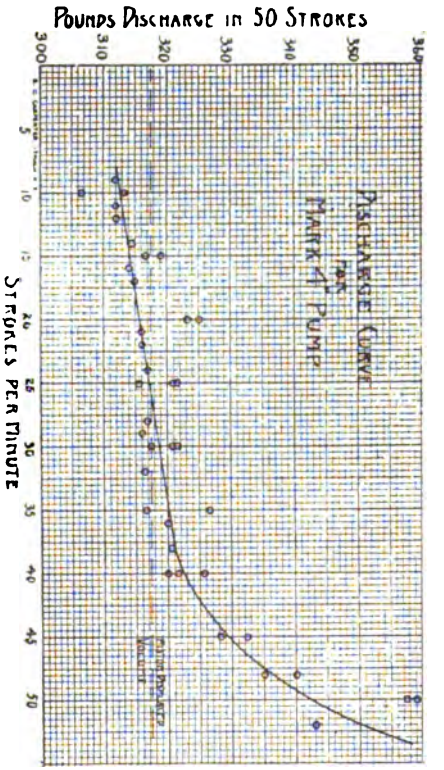

Fig. 14.

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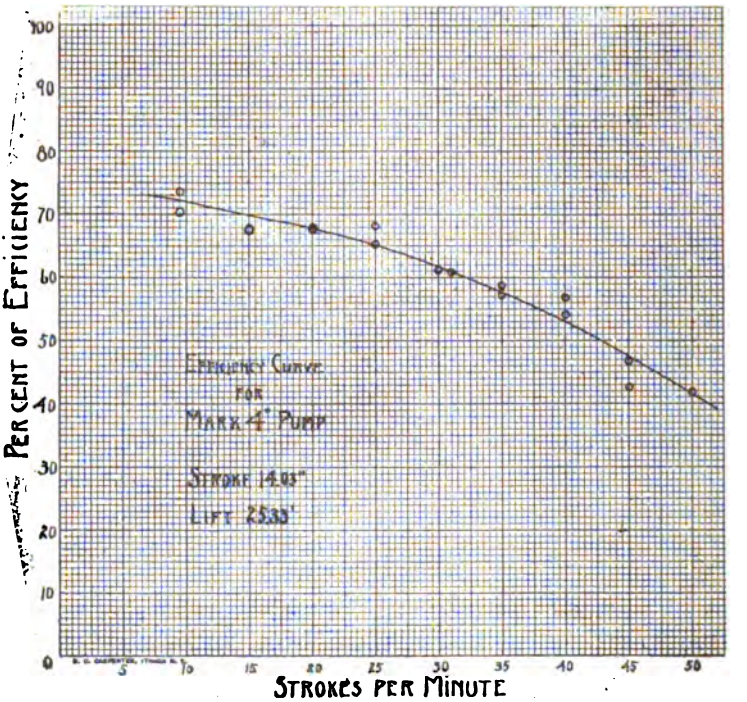

Fig. 15.

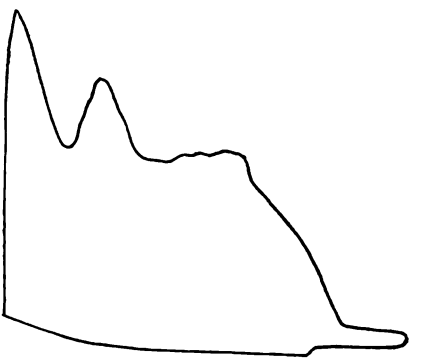

Fig. 16.

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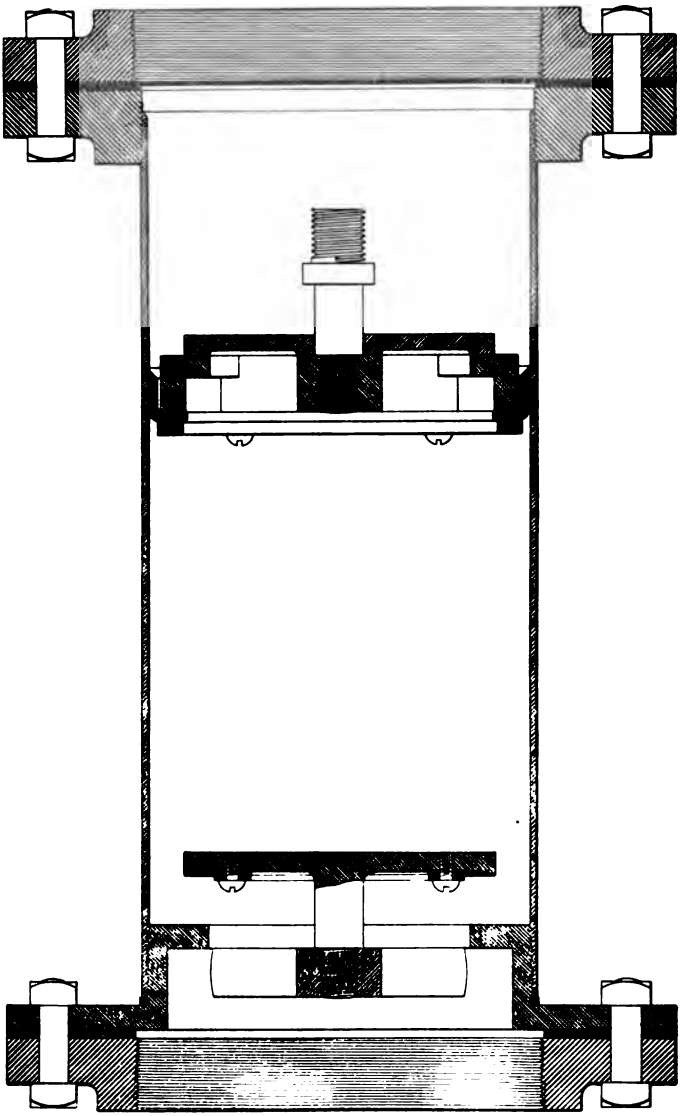

Fig. 17.

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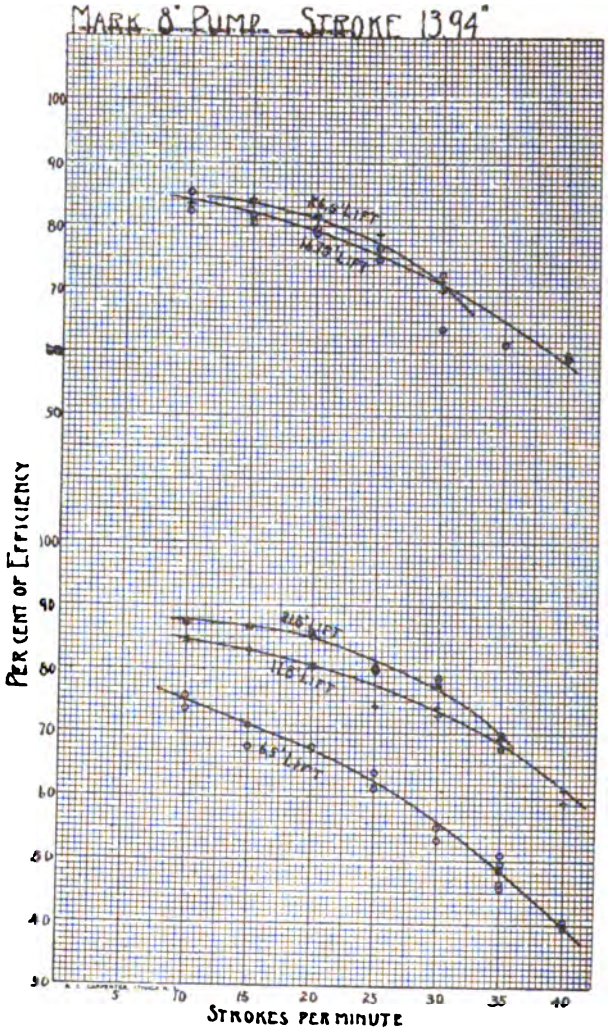

Fig. 18.

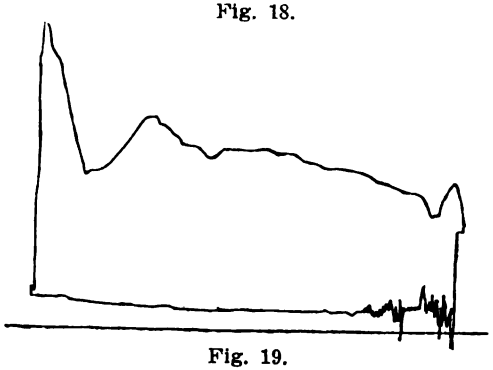

Fig. 19.

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TABLE I. VanVoorhis 8-inch pump. Stroke, 10.02 inches.

LIFT, 4.875 FEET.

Speed.	Discharge in pounds per stroke.	Foot pounds of useful work.	Average pull on rod in pounds.	Foot pounds work given to rod.	Mechanical efficiency, per cent.	Max. tension on the rod, pounds.	Min. tension on the rod, pounds.	Stroke finished at closure of the upper valve, %	Stroke finished at closure of the lower valve, %
8.....	17.65	86.04	180.00	108.55	79.20	235	+85	.....	.....
8.....	17.65	86.04	125.50	104.79	82.10	.....	.....	.....	.....
35.....	14.85	72.39	140.95	117.68	62.00	.....	.....	4	12
40.....	14.30	69.71	147.65	123.28	56.00	515	+20	5	16
40.....	14.30	69.71	151.00	126.00	55.30	.....	.....	5	16
54.....	12.80	62.40	158.30	132.18	47.20	780	−50	11	21
54.....	12.80	62.40	156.65	131.63	47 40	.....	.....	11	21
54.....	12.80	62.40	155.30	129 67	48.20	.....	.....	11	21
54.....	12.80	62.40	157.70	131.69	47.30	675	−35	11	21

LIFT, 5.166 FEET.

15.....	17.05	88.09	154.30	128.84	67.60	.....	.....	.....	2
16.....	16.95	87.57	150.80	125.90	69.55	.....	.....	.....	3
17.....	16.85	86.96	148.65	124.12	70.00	.....	.....	.....	5
20.....	16.50	85.25	150.00	125.25	68.00	285	40	.....	6
23.....	16.20	83.70	145.70	121.66	68.80	280	50	.6	6
26.....	15.85	81,89	153.30	128.00	63.97	.....	.....	.9	9
29.....	15.50	80.08	150.00	125.25	63.92	.....	.....	2	11
36.....	14.75	76.20	150.00	125.25	60.80	490	0	4	15
36.....	14.75	76.20	151.30	126.33	60.30	.....	.....	4	15
43.....	14.00	72.33	167.75	140.07	51.60	550	0	6	16
43+...	13.90	71.81	147.65	123.28	58.20	.....	.....	6	17
46.....	13.65	70.52	154.30	128.67	54.80	575	15	7	19
43+...	13.90	71.81	147.65	123.28	58.20	.....	.....	5	17
49.....	13.35	68.97	150.00	125.25	55.00	.....	.....	5	20
54.....	12.80	66.13	153.30	128.00	51.60	650	0	10	21
54.....	12.80	66.13	153.30	128.00	51.60	.....	.....	10	22
58.....	12.35	63.81	164.04	136.89	46.60	876	−72	12	22
65.....	11.60	59.93	179.46	149.84	40.00	600	0	12	.....
72.....	11.05	55.25	194.32	162.25	34.00	1,200	−75	17	27
84.....	10.55	54.51	285.30	238.22	22.80	.....	.....	20	.....
85.....	10.50	54.24	226.16	188.64	27.80	1,500	−150	21	37
90.....	10.40	53.73	264.12	220.37	24.70	1,200	−160	20	.....
100.....	10.00	50.00	283.72	236.90	21.10	1,560	−135	22	.....

TABLE II.—VanVoorhis 8-inch pump. Stroke, 10.02 inches.

DISCHARGE.

Speed.	Discharge in pounds in 20 strokes.	Discharge in pounds in 20 strokes.	Plotted average; discharge per stroke, lbs.
10.....	348.5	348.5	17.55
15.....	344.5	346	17.05
20.....	332	328	16.50
25.....	315	315.5	15.97
30.....	301	296	15.42
35.....	296	294	14.85
40	289	290	14.30
45.....	281	291	13.77
47.....	373	.....	13.55
50.....	262	259.5	13.35
55.....	249	253	12.80
60.....	244	241.5	12.35
65	227	235	11.60
68.....	220	238	11.35
70	222	219.5	11.05
75.....	221.5	220	10.90
80.....	213	215	10.67
85.....	215.5	208.5	10.55

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TABLE III. Frizell 4-inch pump. Stroke, 23.7 inches.

DISCHARGE.

SPEED.	Discharge in lbs. for 50 strokes. Lift, 24.3 ft.	Discharge in lbs. for 50 strokes. Lift, 24.8 ft.	Discharge in lbs. for 50 strokes. Lift, 37.8 ft.	Discharge in lbs. for 30 strokes. Lift, 12.75 ft.	Discharge in lbs. for 30 strokes. Lift, 6.54 ft.	Plotted average discharge per stroke.
10	.....	451½	462	275⅛	274	9.168
10	.....	457⅛	465	275½	274	.....
15	460	463⅛	466	275½	277	9.2592
15	.....	464	468	275½	278½	.....
20	465	464⅛	467	278	281	9.2724
20	.....	464	468	278	281½	.....
25	467	463⅛	467	278⅛	280	9.3102
25	.....	463½	467½	278¾	280	.....
30	466	469	467	279½	279	9.3272
30	.....	465	467	279½	280	.....
35	472	468	468	279½	281	9.34
35	.....	463½	466⅛	281	280⅛	.....
40	467	466½	466	281	284	9.3546
40	.....	466½	467	280⅛	280	.....
45	467	462½	467½	280⅛	280	9.3328
45	.....	465	467⅛	280	282	.....
50	.....	449½	443	277⅛	279	9.2546
50	.....	.....	.....	279	279	.....
55	.....	.....	.....	171	253	.....
55	.....	.....	.....	.....	267	.....

TABLE IV. Frizell 4-inch pump. Stroke, 23.7 inches.

LIFT, 6.54 FEET.

Speed.	Discharge in pounds per stroke.	Foot pounds of useful work.	Average pull on rod, in pounds.	Foot pounds of work given to rod.	Mechanical efficiency, per cent.	Max. tension on rod, pounds.	Min. tension on rod, pounds.
10	9.168	59.96	79.38	156.77	38.2	120	33
10	9.168	59.96	79.99	158.01	37.9	.....	.....
15	9.2592	60.56	79.15	156.33	38.7	.....	.....
15	9.2592	60.56	78.96	155.94	38.8	.....	.....
20	9.2724	60.64	84.31	161.51	36.4	135	9
20	9.2724	60.64	83.75	165.41	36.6	.....	.....
25	9.31	60.89	77.91	153.81	39.6	.....	.....
25	9.31	60.89	76.04	150.18	40.5	.....	.....
30	9.327	61.00	76.66	151.40	40.2	177	9
30	9.327	61.00	77.91	153.87	39.9	.....	.....
35	9.34	61.08	75.82	149.74	40.7	.....	.....
35	9.34	61.08	77.08	152.23	40.0	195	6
40	9.35	61.18	75.00	148.11	41.2	201	—15
40	9.35	61.18	75.00	148.11	41.2	.....	.....
45	9.33	61.04	76.23	150.55	40.5	258.5	—30
45	9.33	61.04	76.65	151.38	40.3	.....	.....
50	9.25	60.53	75.82	149.74	40.4	249	—24
50	9.25	60.53	78.75	155.50	39.9	.....	.....
55	8.66	56.68	75.82	149.44	37.8	222	—30
55	8.66	56.68	75.41	148.90	38.0	.....	.....

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LIFT, 12.75 FEET.

Speed.	Discharge in pounds per stroke.	Foot pounds of useful work.	Average pull on rod, in pounds.	Foot pounds of work given to rod.	Mechanical efficiency, per cent.	Max. tension on rod, pounds.	Min. tension on rod, pounds.
10	9.168	116.89	89.63	177.00	66	.....	.....
10	9.168	116.89	87.07	171.97	68	.....	.....
15	9.260	118.05	94.90	187.43	63	.....	.....
15	9.260	118.05	98.20	193.11	61	.....	.....
20	9.270	118.22	97.17	191.91	61	.....	.....
20	9.270	118.22	95.77	189.24	62	.....	.....
25	9.310	118.70	97.22	192.00	62	175	30.0
25	9.310	118.70	96.60	190.78	62	.....	.....
30	9.327	118.91	94.63	186.88	63	.....	.....
30	9.327	118.91	97.80	184.82	63	.....	.....
35	9.340	119.08	95.22	188.09	63	.....	.....
35	9.340	119.08	96.45	190.78	63	250	11.5
40	9.350	119.17	109.85	216.95	54	.....	.....
40	9.350	119.17	100.70	198.88	59	.....	.....
45	9.330	118.99	99.57	196.66	60	325	—11.5
45	9.330	118.99	101.40	200.26	59	.....	.....
50	9.250	117.99	95.77	189.24	62	350	—95.0
50	9.250	117.99	96.90	191.54	62	.....	.....
55	5.700	72.67	99.30	196.11	37	375	—75.0

LIFT, 24.8 FEET.

Speed.	Discharge in pounds per stroke.	Foot pounds of useful work.	Average pull on rod, in pounds.	Foot pounds of work given to rod.	Mechanical efficiency, per cent.	Max. tension on rod, pounds.	Min. tension on rod, pounds.
10	9.168	227.36	149.28	294.82	77.1	.....	.....
10	9.168	227.36	147.48	291.27	78.0	.....	.....
15	9.260	229.65	161.28	377.69	72.8	.....	.....
15	9.260	229.65	155.01	306.06	75.3	.....	.....
20	9.270	229.89	155.82	307.74	74.7	.....	.....
20	9.270	229.89	156.66	309.40	74.3	.....	.....
25	9.310	230.89	156.66	309.40	74.6	.....	.....
25	9.310	230.89	154.14	304.34	75.8	.....	.....
30	9.327	231.11	154.14	304.32	75.8	348	—36
30	9.327	231.11	152.46	301.10	76.7	.....	.....
35	9.340	231.63	154.14	304.42	76.8	.....	.....
35	9.340	231.63	162.48	319.23	72.5	.....	.....
40	9.350	231.88	157.59	311.21	74.4	398	—24
40	9.350	231.88	158.73	312.65	74.1	.....	.....
45	9.330	231.38	161.10	319.00	72.5	471	—36
45	9.330	231.38	158.73	312.65	74.0	.....	.....
50	9.250	229.40	153.99	304.13	75.4	.....	.....

LIFT, 30.75 FEET.

Speed.	Discharge in pounds per stroke.	Foot pounds of useful work.	Average pull on rod, in pounds.	Foot pounds of work given to rod.	Mechanical efficiency, per cent.	Max. tension on rod, pounds.	Min. tension on rod, pounds.
10 +	9.168	280.89	176.45	348.50	80.5	250	15
10 +	9.168	280.89	175.05	345.70	81.2	.....	.....
10	9.168	280.89	176.00	347.80	80.7	240	40
10	9.168	280.89	167.60	331.00	84.8	.....	.....
15	9.26	284.72	176.55	348.70	81.6	.....	.....
15	9.26	284.72	176.55	348.70	81.6	.....	.....
20	9.27	285.12	179.25	354.00	80.5	280	40
20	9.27	285.12	181.15	357.80	79.3	.....	.....
25	9.31	286.29	180.65	356.80	80.2	.....	.....
25	9.31	286.29	184.85	365.10	78.1	.....	.....
30	9.327	286.81	180.15	355.80	80.6	370	0
30	9.327	286.81	177.35	350.30	81.8	.....	.....
35	9.34	287.20	190.15	375.60	76.4	425	0
35	9.34	287.20	185.90	367.20	78.2	.....	.....
40	9.35	287.65	197.45	390.00	73.7	490	—25
40	9.35	287.65	198.60	392.20	73.3	.....	.....
45	9.33	286.98	199.70	394.40	72.7	540	—5
45	9.33	286.98	193.25	381.70	75.1	.....	.....
50	9.25	284.58	188.70	372.70	76.3	590	—125

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LIFT, 18.8 FEET.

Speed.	Discharge in pounds per stroke.	Foot pounds of useful work.	Average pull on rod, in pounds.	Foot pounds of work given to rod.	Mechanical efficiency.	Max. tension on rod, pounds.	Min. tension on rod, pounds.
10	9.168	172.36	126.75	250.33	69	180	36
10	9.168	172.36	120.33	237.65	72	.....	.....
15	9.260	174.07	135.21	267.04	65	.....	.....
15	9.260	174.07	133.50	263.66	69	.....	.....
20	9.270	174.32	139.05	274.62	63	.....	.....
20	9.270	174.32	136.89	270.35	64	.....	.....
25	9.310	175.03	148.32	292.93	60	240	24
25	9.310	175.03	142.83	282.09	62	.....	.....
30	9.327	175.35	139.47	275.45	63	.....	.....
30	9.327	175.35	139.47	275.45	63	.....	.....
35	9.340	175.59	141.90	280.25	64	288	3
35	9.340	175.59	145.32	287.00	61	.....	.....
40	9.350	175.86	146.64	289.61	61	336	6
40	9.350	175.86	151.68	299.56	58	.....	.....
45	9.330	175.45	150.42	297.08	59	360	—9
45	9.330	175.45	138.57	278.67	63	.....	.....
50	9.250	173.98	154.62	305.37	56	405	—30
50	9.250	173.98	151.26	299.49	58	.....	.....
55	5.700	107.16	150.42	297.08	36	450	—120
55	5.700	107.16	156.32	308.75	34	.....	.....
58	5.430	102.14	159.72	315.36	32	450	—120
58	5.430	102.14	156.33	308.75	33	.....	.....

LIFT, 37.6 FEET.

Speed.	Discharge in pounds per stroke.	Foot pounds of useful work.	Average pull on rod, in pounds.	Foot pounds of work given to rod.	Mechanical efficiency, per cent.	Max. tension on rod, pounds.	Min. tension on rod, pounds.
10	9.168	344.61	208.32	411.35	83	.....	.....
10	9.168	344.61	208.32	411.35	83	.....	.....
15	9.26	348.14	213.30	421.26	82	275	50
15	9.26	348.14	211.56	417.84	83	.....	.....
20	9.27	348.64	214.98	424.58	82	.....	.....
20	9.27	348.64	220.74	435.93	80	.....	.....
25	9.31	350.06	220.74	435.93	80	360	36
25	9.31	350.06	218.94	432.40	81	.....	.....
30	9.327	350.70	224.16	442.70	79.4	.....	.....
30	9.327	350.70	225.18	444.73	78	.....	.....
35	9.34	351.18	224.34	443.07	79	410	0
35	9.34	351.18	231.00	456.22	77	.....	.....
40	9.35	351.73	231.66	457.36	76	.....	.....
48	9.33	350.91	229.56	453.38	77	.....	.....
48	9.33	350.91	234.30	462.89	75	.....	.....

TABLE V. Frizell 4-inch pump. Stroke, 23.7 inches. Used as a force-pump with a stuffing-box.

LIFT, 24.3 FEET.

Speed.	Discharge in pounds per stroke.	Foot pounds of useful work.	Average pull on rod, in pounds.	Foot pounds of work given to rod.	Mechanical efficiency, per cent.	Max. tension on rod, pounds.	Min. tension on rod, pounds.
10	9.168	222.48	221.08	436.63	51.2	280	24
10	9.168	222.48	225.52	445.40	50.	.....	.....
15	9.260	225.02	223.32	441.06	53.2	.....	.....
15	9.260	225.02	218.88	432.28	54.4	.....	.....
20	9.270	225.26	217.76	430.07	52.3	.....	.....
20	9.270	225.26	218.88	432.28	52.1	.....	.....
25	9.310	226.32	211.08	416 88	54.2	308	—32
25	9.310	226.32	217.76	430.07	52.6	.....	.....
30	9.327	226.60	217.56	429.56	52.0	376	—82
30	9.327	226.60	216.60	427.78	52.9	.....	.....
35	9.340	227.12	221.08	436.63	52.1	.....	.....
35	9.340	227.12	220.96	448.56	50.6	.....	.....
40	9.350	229.55	217.68	449.08	51.1	.....	.....
40	9.350	229.55	215.44	425.47	53.9	.....	.....
45	9.330	224.69	215.44	425.47	52.8	520	—88
45	9.330	224.69	213.44	431.82	52.3	.....	.....

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TABLE VI. Frizell 4-inch pump. Stroke, 23.7 inches. Used as a force pump and delivering water against air pressure equivalent to the lift noted.

LIFT, 47.37 FEET.

Speed.	Discharge in pounds per stroke.	Foot pounds of useful work.	Average pull on rod, in pounds.	Foot pounds of work given to rod.	Mechanical efficiency, per cent.	Max. tension on rod, pounds.	Min. tension on rod, pounds.
10	9.168	434.29	348.60	695.78	62.4	.....	.....
10	9.168	434.29	369.60	729.96	59.4	.....	.....
15	9.26	438.60	376.20	734.66	59.7	.....	.....
15	9.26	438.60	360.30	711.59	61.6	.....	.....
20	9.27	439.21	361.32	713.61	61.5	.....	.....
20	9.27	439.21	360.00	711.00	61.7	444	—18
25	9.31	441.01	366.66	724.16	60.9	.....	.....
25	9.31	441.01	360.00	711.00	62.0	.....	.....
30	9.327	441.82	378.30	747.14	59.1	.....	.....
30	9.327	441.82	383.58	757.48	58.3	.....	.....
35	9.34	442.44	380.33	751.15	58.9	636	—108
35	9.34	442.44	380.00	750.50	58.9	.....	.....
40	9.35	442.90	385.44	761.23	58.1	.....	.....
40	9.35	442.90	385.32	761.00	58.2	.....	.....
45	9.33	441.96	402.24	794.34	56.9	756	—90
45	9.33	441.96	413.32	816.30	54.1	.....	.....

LIFT, 70.5 FEET.

SPEED.	Discharge in pounds per stroke.	Foot pounds of useful work.	Average pull on rod, in pounds.	Foot pounds of work given to rod.	Mechanical efficiency, per cent.	Max. tension on rod, pounds.	Min. tension on rod, pounds.
10	9.168	646.34	495.75	895.77	72.1	.....	.....
10	9.168	646.34	510.00	1007.00	64.5	.....	.....
15	9.26	652.83	515.33	1101.11	59.2	.....	.....
15	9.26	652.83	514 50	1016.22	64.2	.....	.....
20	9.27	653.54	508.35	1003.90	65.0	.....	.....
20	9.27	653.54	513.22	1013.62	64.4	.....	.....
25	9.31	656.36	536.25	1059.09	61.9	.....	.....
25	9.31	656.36	534.15	1054.96	62.2	.....	.....
30	9.327	657.55	532.13	1050.95	62.5	.....	.....
30	9.327	657.55	527.85	1042.50	63.0	.....	.....
35	9.34	658.47	521.53	1030.02	63.8	780	—75
35	9.34	658.47	515.33	1101.11	59.8	.....	.....
40	9.35	659.18	532.13	1050.96	62.7	.....	.....
40	9.35	659.18	516.66	1020.32	64.6	825	—165
45	9.33	657.77	525.60	1038.06	63.3	.....	.....
45	9.33	657.77	525.60	1038.06	63.3	.....	.....

TABLE VII. Discharge of Frizell 6-inch pump.

Speed.	Discharge in 30 strokes, lift 7.66 feet.	Discharge in 30 strokes, lift 12.66 feet.	Discharge in 30 strokes, lift 32.75 feet.	Plotted averages, per stroke.
10	378	367	377	12.50
10	377	.....	378	.....
15	377	371	380	12.56
15	379	371	383½	.....
20	377	373½	381½	12.57
20	378½	372½	.....	.....
25	382	370	380	12.55
25	.....	370	382	.....
30	375	368½	381½	12.52
30	379	369	376	.....
35	374	371	377½	12.47
35	371	365	374½	.....
40	379	370	379	12.44
40	375½	365½	374½	.....
45	374	365½	376	12.40
45	373	367	373	.....
50	377½–378	372	370½	12.36
50	380 –379	364	369	.....
50	371½–374	.....	.....	.....
55	383	364	.....	12.30
55	371 –370	359	.....	.....
60	372	361	.....	12.22
60	371 –371	357	.....	.....

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TABLE VIII. Frizell 6-inch pump. Stroke, 14.112 inches.

LIFT, 7.66 FEET.

Speed.	Discharge in pounds per stroke.	Foot pounds of useful work.	Average pull on rod, in pounds.	Foot pounds of work given to rod.	Mechanical efficiency, per cent.	Max. tension on rod, pounds.	Min. tension on rod, pounds.
10	12.50	95.75	106.37	124.11	77.1	.....	.....
10	12.50	95.75	111.70	131.36	72.8	.....	.....
15	12.56	96.21	124.45	146.35	66.4	.....	.....
15	12.56	96.21	127.65	150.12	64.1	.....	.....
20	12.57	96.28	124.45	146.35	65.7	.....	.....
20	12.57	96.28	123.40	145.12	66.3	.....	.....
25	12.55	96.13	122.35	143.88	66.8	.....	.....
25	12.55	96.13	122.88	144.50	66.5	.....	.....
30	12.52	95.90	123.40	145.12	66.0	.....	.....
30	12.52	95.90	121.30	142.65	67.2	.....	.....
35	12.47	95.52	121.30	142.65	66.9	.....	.....
35	12.47	95.52	125.53	147.61	64.7	.....	.....
40	12.44	95.29	125.53	147.61	64.5	.....	.....
40	12.44	95.29	125.53	147.61	64.5	.....	.....
45	12.40	94.98	125.53	147.61	64.3	.....	.....
45	12.40	94.98	124.45	146.35	64.9	.....	.....
50	12.36	94.68	126.56	148.84	63.6	800	—30
50	12.36	94.68	128.16	150.72	62.8	.....	.....
55	12.30	94.22	128.16	150.72	62.5	.....	.....
55	12.30	94.22	128.16	150.72	62.5	.....	.....
60	12.22	93.60	128.16	150.72	62.1	.....	.....
60	12.22	93.60	129.26	152.00	61.5	.....	.....

LIFT, 32.75 FEET.

Speed.	Discharge in pounds per stroke.	Foot pounds of useful work.	Average pull on rod, in pounds.	Foot pounds of work given to rod.	Mechanical efficiency, per cent.	Max. tension on rod, pounds.	Min. tension on rod, pounds.
10	12.50	409.38	435.38	512.00	81.3	.....	.....
10	12.50	409.38	431.25	507.15	80.7	.....	.....
15	12.56	411.34	441.60	519.32	79.2	.....	.....
15	12.56	411.34	444.90	523.20	78.6	.....	.....
20	12.57	422.06	440.40	517.91	81.5	.....	.....
20	12.57	422.06	441.60	591.32	81.7	.....	.....
25	12.55	421.41	429.00	504.50	83.5	.....	.....
25	12.55	421.41	435.38	512.00	82.1	.....	.....
30	12.52	420.43	425.85	500.90	83 9	720	—30
30	12.52	420.43	431.25	507.15	82.9	.....	.....
35	12.47	408.39	424.42	499.12	81.8	.....	.....
35	12.47	408.39	424.42	499.12	81.8	.....	.....
40	12.44	407.41	430.80	506.62	81.3	.....	.....
40	12.44	407.41	435.03	510.42	79.8	1,050	—97.5
45	12.40	406.10	425.20	500 04	81.1	1,027.5	—90
45	12.40	406.10	419.47	493.29	82.9	.....	.....
50	12.36	404.79	425.20	500.04	80.9	.....	.....
50	12.36	404.79	425.20	500.04	80.9	1,260	—60

LIFT, 37.75 FEET.

Speed.	Discharge in pounds per stroke.	Foot pounds of useful work.	Average pull on rod, in pounds.	Foot pounds of work given to rod.	Mechanical efficiency, per cent.	Max. tension on rod, pounds.	Min. tension on rod, pounds.
10	12.50	471.87	484.25	573.97	82.2	.....	.....
10	12.50	471.87	484.87	566.68	83.2	.....	.....
15	12.56	474.14	478.72	562.97	85.3	.....	.....
15	12.56	474.14	475.50	559.19	84.7	.....	.....
20	12.57	474.52	476.62	560.40	84.6	.....	.....
20	12.57	474.52	479.77	564.21	84.1	.....	.....
25	12.55	473.76	493.52	579.20	81.7	750	0
25	12.55	473.76	486.22	561.79	84.8	.....	.....
30	12.52	472.63	483.00	568.00	83.2	.....	.....
30	12.52	472.63	495.75	583.00	81.0	.....	.....
35	12.47	470.74	492.52	579.20	81.2	.....	.....
35	12.47	470.74	483.00	568.00	82.8	1,020	—67.5
40	12.44	469.61	489.38	575.51	81.6	.....	.....
40	12.44	469.61	486.22	571.79	82.3	1,005	—67.5
45	12.40	468.10	486.22	571.79	81.9	.....	.....

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LIFT, 12.66 FEET.

Speed.	Discharge in pounds per stroke.	Foot pounds of useful work.	Average pull on rod, in pounds.	Foot pounds of work given to rod.	Mechanical efficiency, per cent.	Max. tension on rod, pounds.	Min. tension on rod, pounds.
10	12.50	158.25	191.45	225.15	70.3	300	65
10	12.50	158.25	192.80	226.70	69.8	.....	.....
15	12.56	159.00	186.95	220.25	72.1	310	40
15	12.56	159.00	187.75	220.79	72.0	.....	.....
20	12.57	159.14	181.40	213.33	74.6	.....	.....
20	12.57	159.14	189.35	223.67	71.4	.....	.....
25	12.55	158.98	187.20	220.15	72.2	.....	.....
25	12.55	158.98	188.55	221.74	71.7	.....	.....
30	12.52	158.50	192.80	226.73	69.9	.....	.....
30	12.52	158.50	191.45	225.15	70.3	.....	.....
35	12.47	157.86	191.45	225.15	70.1	.....	.....
35	12.47	157.86	191.45	225.15	70.1	.....	.....
40	12.44	157.49	189.35	222.67	70.7	.....	.....
40	12.44	157.49	191.45	225.15	69.9	750	—75
45	12.40	156.98	190.65	224.21	70.0	750	—80
45	12.40	156.98	185.10	217.68	72.1	.....	.....
50	12.36	156.58	187.70	219.15	75.9	.....	.....
50	12.36	156.58	191.44	228.66	68.4	.....	.....
55	12.30	155.72	188.55	221.74	70.2	850	—70
55	12.30	155.72	188.55	221.74	70.2	.....	.....
60	12.22	154.70	192.80	226.73	68.2	.....	.....
60	12.22	154.70	180.35	222.67	69.4	.....	.....

LIFT, 22.66 FEET.

Speed.	Discharge in pounds per stroke.	Foot pounds of useful work.	Average pull on rod, in pounds.	Foot pounds of work given to rod.	Mechanical efficiency, per cent.	Max. tension on rod, pounds.	Min. tension on rod, pounds.
10	12.50	283.25	277.50	326.34	86.7	410	60
10	12.50	283.25	.....	.....	80.6	.....	.....
15	12.56	284.61	279.65	328.87	86.4	.....	.....
15	12.56	284.61	277.50	326.34	87.2	.....	.....
20	12.57	284.84	277.50	326.34	87.3	.....	.....
20	12.57	284.84	277.50	326.34	87.3	.....	.....
25	12.55	284.38	282.70	332.35	85.6	.....	.....
25	12.55	284.38	280.60	329.98	86.2	.....	.....
30	12.52	283.70	282.70	332.35	85.3	500	—85
30	12.52	283.70	284.80	334.92	84.4	.....	.....
35	12.47	282.56	291.10	342.33	82.6	.....	.....
35	12.47	282.56	295.35	347.33	81.3	.....	.....
40	12.44	281.89	295.35	347.33	81.0	770	—85
40	12.44	281.89	291.10	342.33	82.3	.....	.....
45	12.40	280.98	291.10	342.33	81.8	.....	.....
45	12.40	280.98	284.80	332.12	84.6	930	—50
50	12.36	280.08	294.40	346.12	80.9	925	—100
50	12.36	280.08	295.35	347.33	80.6	.....	.....
55	12.30	278.72	292.10	343.39	81.1	.....	.....
55	12.30	278.72	291.10	342.33	81.4	1,050	—100
60	12.22	276.90	290.25	341.34	81.1	.....	.....
60	12.22	276.90	296.20	348.33	79.4	.....	.....

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TABLE IX. Mark 4-inch pump. Stroke, 14.03 inches.

Speed.	Discharges in 50 strokes, lift 25 feet.	Plotted averages of discharge, per stroke.
9.....	312	.....
10.....	306⅔–313⅓	6.25
11.....	312	.....
12.....	312	.....
14.....	314½	.....
15.....	316⅔–319	6.28
16.....	314	.....
17.....	315	.....
20.....	325 –323½	6.314
21.....	316	.....
22.....	316	.....
24.....	317	.....
25.....	320.8–322½	6.344
25.....	315½	.....
28.....	317	.....
29.....	316	.....
30.....	320.8–321½	6.37
30.....	317½	.....
34.....	316½	.....
35.....	326⅔–316⅔	6.40
36.....	320	.....
38.....	320½	.....
40.....	321⅔–325.8–320	6.45
45.....	328¼–322½	6.59
48.....	340	.....
50.....	357½–359	6.84
52.....	343	.....

TABLE X. Mark 4-inch pump. Stroke, 14.03 inches.

LIFT, 25.33 FEET.

Speed.	Discharge in pounds per stroke.	Foot, pounds of useful work.	Average pull on the rod, in pounds.	Foot, pounds of work given to the rod.	Mechanical efficiency, per cent.
9¼.....	6.250	158.23	183.00	214.79	73.6
9¼.....	6.250	158.23	195.37	227.93	70.2
15.....	6.280	159.09	201.20	235.23	67.6
15.....	6.280	159.09	200.75	234.71	67.6
20.....	6.314	159.95	201.20	235.23	67.9
20.....	6.314	159.95	201.42	235.49	67.9
25.....	6.344	160.72	210.70	246.34	65.2
25.....	6.344	160.72	202.60	236.87	68.2
32.....	6.390	161.88	227.37	265.83	60.9
30.....	6.370	161.37	225.00	263.06	61.2
30.....	6.370	161.37	228.57	267.23	61.1
35.....	6.400	162.13	241.92	282.84	57.3
35.....	6.400	162.13	235.40	275.22	58.9
40.....	6.450	164.40	260.24	304.31	54.0
40.....	6.450	164.40	246.73	288.47	56.9
45.....	6.590	166.94	304.60	356.12	46.8
45+.....	6.600	167.20	335.84	392.65	42.5
50.....	6.840	173.28	364.28	414.21	4.18

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TABLE XI. Mark 8-inch pump. Stroke, 13.94 inches.

Speed.	Discharge for 15 strokes, lift 6.5 feet.	Discharge for 15 strokes, lift 11.8 feet.	Discharge for 15 strokes, lift 26.5 feet.	Plotted average discharge per stroke.
10	367½	371	358	24.80
10	369½	369	355½	.....
15	366½	368½	358¼	24.80
15	368	362½	357½	.....
20	368	369½	358	24.80
20	365½	367	358½	.....
25	365	369½	355¼	24.266
25	365	370½	358¾	.....
30	358	367	351½	24.00
30	358	361½	351¾	.....
35	346½	358	.....	23.60
35	348	356½	.....	.....
40	337½	359	.....	23.20
40	352	357	.....	.....

TABLE XII. Mark 8-inch pump. Stroke, 13.94 inches.

LIFT, 6.5 FEET.

Speed.	Discharge in pounds per stroke.	Foot, pounds of useful work.	Average pull on the rod, in pounds.	Foot, pounds of work given to the rod.	Mechanical efficiency, per cent.	Max. tension on the rod, pounds.	Min. tension on the rod, pounds.
10	24.300	157.95	184.72	214.28	73.7	312	72
10	24.300	157.95	179.64	208.38	75.7	.....	.....
15	24.300	157.95	200.00	232.36	67.9	.....	.....
15	24.300	157.95	191.52	222.16	71.1	.....	.....
20	24.300	157.95	200.00	232.36	67.9	.....	.....
20	24.300	157.95	200.16	232.50	67.8	.....	.....
25	24.266	157.73	213.36	247.50	63.7	.....	.....
25	24.266	157.73	220.32	255.57	61.3	.....	.....
30	24.000	156.00	244.04	283.08	55.1	.....	.....
30	24.000	156.00	252.52	292.92	53.2	648	—72
35	23.600	153.40	284.72	330.28	46.4	.....	.....
35	23.600	153.40	271.16	314.55	48.7	664	—80
35	23.600	153.40	289.80	336.17	45.6	.....	.....
35	23.600	153.40	259.32	300.81	50.9	738	—108
35	23.600	153.40	266.94	309.65	49.5	.....	.....
40	23.200	150.80	325.38	377.44	39.7	.....	.....
40	23.200	150.80	320.04	371.25	40.5	.....	.....

LIFT, 11.8 FEET.

Speed.	Discharge in pounds per stroke.	Foot, pounds of useful work.	Average pull on the rod, in pounds.	Foot, pounds of work given to the rod.	Mechanical efficiency, per cent.	Max. tension on the rod, pounds.	Min. tension on the rod, pounds.
10	24.30	286.74	293.60	340.58	84.2	480	70
10	24.30	286.74	290.60	337.10	85.0	.....	.....
15	24.30	286.74	297.00	344.52	83.2	.....	.....
15	24.30	286.74	298.05	345.74	82.9	.....	.....
20	24.30	286.74	308.50	357.86	80.2	.....	.....
20	24.30	286.74	305.55	354.44	80.8	.....	.....
25	24.266	286.34	311.95	385.06	74.3	.....	.....
25	24.266	286.34	311.95	385.06	74.3	.....	.....
30	24.00	283.20	328.95	381.58	74.2	.....	.....
30	24.00	283.20	335.45	389.12	72.8	650	—25
35	23.60	278.48	346.80	402.29	69.2	700	—80
35	23.60	278.48	346.80	402.29	69.2	.....	.....
40	23.20	273.76	384.60	446.14	61.3	.....	.....
40	23.20	273.76	395.30	458.55	59.4	1,140	—100

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LIFT, 16.75 FEET.

SPEED.	Discharge in pounds per stroke.	Foot, pounds of useful work.	Average pull on the rod, in pounds.	Foot, pounds of work given to the rod.	Mechanical efficiency, per cent.	Max. tension on the rod, pounds.	Min. tension on the rod, pounds.
10	24.30	407.03	426.22	494.68	82.3	585	60
10	24.30	407.03	419.85	487.45	85.1	.....	.....
15	24.30	407.03	435.90	506.08	80.4	.....	.....
15	24.30	407.03	429.45	498.16	81.7	.....	.....
20	24.30	407.03	445.50	516.78	78.7	.....	.....
20	24.30	407.03	441.97	512.69	79.5	.....	.....
25	24.266	406.47	458.32	531.66	76.4	.....	.....
25	24.266	406.47	467.92	542.79	74.8	.....	.....
30	24.00	402.00	477.52	552.93	72.5	900	0
30	24.00	402.00	529.72	619.48	63.9	.....	.....
35	23.60	395.30	555.30	644.15	61.3	1,170	—150
40	23.20	388.60	558.45	647.80	59.9	1,245	—150
40	23.20	388.60	564.82	655.20	59.3	.....	.....

LIFT, 21.8 FEET.

Speed.	Discharge in pounds per stroke.	Foot, pounds of useful work.	Average pull on the rod, in pounds.	Foot, pounds of work given to the rod.	Mechanical efficiency, per cent.	Max. tension on the rod, pounds.	Min. tension on the rod, pounds.
10	24.300	529.74	536.18	607.67	87.1	825.0	75.0
10	24.300	529.74	536.18	607.67	87.1	.....	.....
15	24.300	529.74	539.47	611.40	86.6	.....	.....
15	24.300	529.74	539.47	611.40	86.6	.....	.....
20	24.300	529.74	549.30	622.54	85.1	.....	.....
20	24.300	529.74	546.00	618.80	85.6	960.0	75.0
25	24.266	529.01	582.24	659.87	80.2	997.5	—37.5
25	24.266	529.01	583.65	661.47	79.9	.....	.....
30	24.000	523.20	595.35	674.73	77.5	.....	.....
30	24.000	523.20	595.35	674.73	77.5	.....	.....
30	24.000	523.20	585.52	663.59	78.8	.....	.....
35	23.600	514.48	684.15	775.37	69.8	1,387.5	—165.0
35	23.600	514.48	707.17	811.46	67.5	.....	.....

LIFT, 26.5 FEET.

Speed.	Discharge in pounds per stroke.	Foot, pounds of useful work.	Average pull on the rod, in pounds.	Foot, pounds of work given to the rod.	Mechanical efficiency, per cent.	Max. tension on the rod, pounds.	Min. tension on the rod, pounds.
10	24.300	643.95	684.15	775.37	83.5	997.5	45.0
10	24.300	643.95	680.85	771.83	83.6	.....	.....
15	24.300	643.95	677.62	767.97	83.8	.....	.....
15	24.300	643.95	674.32	764.23	84.2	.....	.....
20	24.300	643.95	694.05	786.59	81.8	.....	.....
20	24.300	643.95	697.35	790.33	81.4	.....	.....
25	24.266	643.06	720.37	816.42	78.7	1,275.0	—37.5
25	24.266	643.06	740.77	839.44	76.6	.....	.....
30	24.000	630.00	786.15	890.97	71.3	.....	.....
30	24.000	630.00	801.67	908.56	69.9	.....	.....

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SUMMARY.

So far as the tests go, the following is shown:

1. The efficiency of pumps, all having a right to be called good pumps, may vary from 20 per cent. to 85 per cent., depending on the lift and piston speed.

2. A fall of 25 per cent. in the efficiency of a pump in the usual range of windmill speeds is not uncommon.

3. A pump having a variation of only 5 per cent. is possible.

4. For wells about 20 feet deep there is no need of using a pump of less than 75 per cent. efficiency for average speeds.

5. Two pumps may compare very favorably at a certain lift and much less favorably at some other lift not very much different.

6. A pump having an efficiency of over 80 per cent. at piston speeds up to 100 feet per minute is possible at a 20-foot lift.

7. Some pumps can be run at a piston speed of 180 feet per minute and maintain an efficiency above 70 per cent. for lifts above 20 feet.

8. A pump with very large clack valves on a very low lift may give an efficiency from 80 per cent. at slow speed to 50 per cent. at a piston speed of 80 feet per minute.

9. Pumps at slow speed and high speed discharge a little less water per stroke than at medium speed. This may be from 1 to 2 per cent.

10. A pump with small delivery pipe may at high speed deliver a considerably larger amount of water than that computed from the cylinder capacity.

11. With pumps having an ample supply of water, the speed may be limited by the failure of the lower valve if its movement is not limited.

12. Valves of limited movement are preferable for fast speeds.

13. The addition of a stuffing-box to any form of pump may seriously reduce the efficiency.

14. The initial stress on the up stroke at higher speeds is the destructive element on the windmill. The use of a device to reduce this is well worth consideration. At piston speeds of only 70 per minute, this sudden jerk may be two or three times the weight of the column of water lifted.

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Power and Efficiency of Windmills.

By E. C. MURPHY.

It was a part of the plan of the Board to make some tests of the power and efficiency of windmills, to arrive as near as possible at the proper relation between the power and the pump. Before the Board had reached any definite conclusion as to its method of procedure in this matter, it learned that Prof. E. C. Murphy, of the State University, had been employed by the United States Geological Survey to do work of a similar nature. The Board deferred its action, awaiting the results of Professor Murphy's experiments, which were carried on throughout the season of 1896. Through the courtesy of Mr. F. H. Newell, Chief Hydrographer of the United States Geological Survey, Professor Murphy was permitted to use, in an article for our report, the facts and data acquired by him in his experiments. This investigation is upon entirely new lines and the results reached are interesting and novel. Below we give Professor Murphy's article in full, which is a synopsis of part of his report to the United States Geological Survey.

It is surprising how little definite information there is in regard to the useful work windmills—and especially the steel back-geared mills—of the present day are doing. Thousands, and perhaps millions, are in use for doing work of various kinds, and yet very few careful measurements have been made to determine their horse-power or the number of foot pounds of work they are doing in different wind velocities.

It was to supply in a measure this lack that, two years ago, the writer undertook to measure, with instruments then at his disposal, the pumping power of windmills. This year, with much better facilities furnished by the hydrographic branch of the United States Geological Survey, he has continued this work, extending it to include power as well as pumping mills. We have not attempted to measure the power of every make of mill. This was impossible. It was thought best to confine the work to different sizes of the standard mills—those that are used to a large extent, and are giving satisfaction. In some cases, two or three tests of the same size and make of mill were made for the purpose of showing the influence of the pump or well on the useful work done.

Perhaps nowhere in the United States is irrigation from wells by the use of windmills so extensively practiced as in the vicinity of Garden City, Kas. Here are found hundreds of windmill pumping plants, irrigating from 1 to 15 acres, the pumps lifting from 3 to 14½ quarts per stroke a height of from 10 to 45 feet. Here are found the large steel mills, with the latest improvements, running day and night whenever the wind velocity is sufficiently great. These reasons induced the writer to select this locality as the field of his investigations.

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The report contains a description of the wells and pumps of this locality, which is omitted in this summary, as these facts are included in other reports.

INSTRUMENTS AND METHODS.

The wind velocity was measured with a United States weather bureau cup anemometer. Each mile of wind was recorded electrically by one pen of a two-pen register. By means of a little device fastened to the pump an electric circuit is closed at each stroke of the pump, and a record made by a recorder. Another electric circuit leading from the recorder to other pen of register is closed at each 100 strokes of pump, and a record made on register; hence, the graphic record of register shows the number miles of wind in any given time, and also the number hundred strokes of pump in the same time.

The anemometer was held on a pole at the height of the axis of the wheel of windmill. The pole was made so that its length could be increased at will from 25 to 50 feet.

The discharge per stroke of pump was found by catching the discharge for several strokes in a tub, and measuring this in a quart measure. This was found to vary with the number of strokes per minute in a few cases on account of valves leaking. The discharge given where it varied is for nearly a maximum speed of pump. The lift or distance from surface of water in well to center of water column as it leaves the discharge pipe was measured when the pump was working quite rapidly. For pump on well points it was estimated from the depth to water when point was put down, making an allowance for the pumping down of the water.

DESCRIPTION OF MILLS AND PUMPS TESTED.

Mill No. 2 is a 12-foot Woodmansee Mogul, manufactured by Woodmansee, Hewitt Manufacturing Company, Freeport, Ill. The tower is steel, 50 feet high to axis of wheel. The wind exposure is not good from the north, the mill being 115 feet south of a large barn. The wheel has 30 curved fans, each 36x13x5½ inches, set at an angle of 30 deg. with the plane of wheel. It is back-geared 3 to 1, and held in the wind by a spring. The pump is Woodmansee make. The cylinder is 9½ inches in diameter; supply pipe, 5⅝ inches in diameter; length of stroke, 12 inches. The well is 3¾x3¾ feet square, a distance of 14 feet to water. In the bottom of this is put down a 12-inch galvanized iron pipe 20 feet into water, forming a small open well. The lift at the time of test was 17¾ feet, and the discharge per stroke 14½ quarts. The mean pressure was 26.98 inches, and mean temperature 94 deg. F. The cost of mill, tower, pump and well was about $210.

Mill No. 3 is a 12-foot Aermotor, manufactured by the Aermotor Company, Chicago, Ill. This mill had been in use about a year and all the parts were in good working order. The tower is made of wood, having axis of wheel 30 feet above the ground. The exposure is very good. The wheel has 18 curved fans, each 44x18¾x7¾ inches, set at an angle of 31 deg. to the plane of wheel. It is back-geared 3⅛ to 1, and is held in the wind by a spring. The pump is Stone make, in which the check valve is of the single flap variety, and the plunger of the double flap variety. The cylinder is 9½ inches in diameter, the supply pipe 4 inches in diameter, and the discharge pipe 10 inches outside diameter. The length of stroke is 12 inches, and the discharge per stroke 14½ quarts. The well is 4x4 feet nearly to water, a depth of 8 feet. From this to a depth of 18 feet it is 3 feet in diameter, then in the bottom of this are three 12-inch pipes extending down 5 feet farther. The lift at the time of testing was 13¾ feet. The pressure

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was 27.2 inches, and the temperature 85 deg. F. The water is pumped into a pond 80x75 feet, and a depth of 22 inches can be drawn off. The cost of plant, including mill, tower, pump, and pond, was $145.

Mill No. 4 is an 8-foot Ideal, manufactured by Stover Manufacturing Company, Freeport, Ill. This mill had been in use about one year, and all the parts were in good condition. The tower is of wood; axis of wheel 48 feet above the ground. The wheel has 15 fans, each 16⅛x7x30 inches, set at an angle of 29 deg. with plane of wheel. It is back-geared 2½ to 1, and is held in the wind by a spring. The pump is of Stone make. The discharge pipe is 5⅝ inches in diameter, and the supply pipe 3 inches in diameter. The length of stroke is 8 inches. The plunger and check valves are of the single flap variety. The well is 2¾x2¾ feet down nearly to water, a depth of 5¼ feet. The 3-inch supply pipe extends down to a depth of 14 feet, and on the end of it is a 3-inch well point 6 feet long. The lift may vary from 8½ to 20 feet. It was probably about 12 feet at the time of the test. The discharge per stroke was 2 quarts. The mean pressure was 27.19, and the mean temperature 83 deg. F. The water is pumped into a pond 115x31 feet and 3 feet deep. The cost of plant, including mill, pump, well and pond, was $80.

Mill No. 5 is an 8-foot Aermotor, manufactured by the Aermotor Company, Chicago, Ill. The tower is of wood, and is 28½ feet high to axis of wheel. The exposure is good, and all the parts were in good working order at time of visit, the plant having been in use about one year. The wheel has 18 curved fans, each 30x12½x5½ inches, making an angle of 29½ deg. with plane of wheel. It is back-geared 3½ to 1. The pump is Stone make; discharge pipe, 6 inches diameter; supply pipe, 3 inches diameter. The valves are both of the single flap variety. The length of stroke is 8 inches. The well is 4x4 feet to water, a depth of 10½ feet. A 12-inch wooden curb extends 12 feet further into the sand and gravel. The discharge per stroke was 3½ quarts, and the lift 13 feet. The water is pumped into a pond 110x30x2½ feet. The cost of plant, including pond, was $80.

Mill No. 6 was an 8-foot Gem, manufactured by the U. S. Wind Engine and Pump Company, Kansas City, Mo. The exposure is good, and all the parts in good working order, the mill having been in use only about a year. The mill has 24 curved fans, each 30½x10x4½ inches, set at an angle of 35 deg. with plane of wheel. It is back-geared 3 to 1. The wheel is held in the wind by means of a weight. The pump is Stone make; discharge pipe, 6 inches diameter; supply pipe, 4 inches diameter; length of stroke, 8 inches. The well is open to water, a depth of 6½ feet. The supply pipe is on a well point, the end of which is 16 feet below surface of ground. The lift was 9⅞ feet, and the discharge 3.9 quarts per stroke. The tower is built of wood, and is 24 feet high to axis of wheel. The mean pressure was 27.02 inches, and mean temperature 85 deg. F. The plunger valve is of the double flap variety, and the check of the single flap variety.

Mill No. 7 is a 12-foot Aermotor, similar to mill No. 3. The tower is steel, having a height of 31 feet to axis of wheel. The exposure was good, and all the parts in good working order, the plant having been in use less than one year. The pump is Stone's make, and is like that with mill No. 3, except that the check valve is of the solid lift variety. The lift was 15½ feet, and the discharge 14.3 quarts per stroke. The water is pumped into a pond 135x50x2½ feet.

Mill No. 8 is a 10 foot Star wooden mill, manufactured by Bradley, Wheeler & Co., Kansas City, Mo. The tower is made of wood, and the axis of wheel is 35½ feet above the ground. The water is pumped into an elevated tank 20 feet above the surface of ground, and is used for irrigation. The wheel has 60 plain fans, each 37x5x2¾ inches, set at an angle of 33 deg. to the plane of wheel. It

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is held in the wind by means of a weight. It is not back-geared, a stroke of the pump being made to each revolution of the wheel. The supply pipe is 2 inches diameter, and terminates in a well point, the end of which is 18 feet below the surface of ground. The cylinder is 3 inches diameter, discharge pipe 1¼ inches diameter, length of stroke 5 inches. The lift may vary between 28½ and 37 feet. It was estimated to be about 30 feet at the time of measurement. The discharge per stroke was .24 quart. The cylinder leaked some at the time of test. After a new cylinder was put in the discharge per stroke was increased to .40 quart. The mean pressure was 27.04 inches; mean temperature, 78 deg. F.

Mill No. 9 is a 16-foot Aermotor. The tower is of steel; axis of wheel 30 feet above the ground. The wheel has 18 curved fans, each 59x25¾x10½ inches, set at an angle of 30 deg. with plane of wheel. It is back-geared 3⅓ to 1. The discharge pipe is 12 inches in diameter; supply pipe, 6 inches diameter; cylinder, 8 inches diameter; stroke, 16 inches. The well is 4x6 feet to a depth of 23 feet; 2x2 feet down 8 feet further, and 18 inches diameter down 14 feet further. The water is 39½ feet below the surface of the ground. The lift is 44¼ feet and the discharge 11 quarts per stroke. The check valve is of the single flap variety, and the plunger the double flap variety. The mean pressure was 27.04 inches, and the mean temperature 93 deg. F. This plant has been in use about three years.

Mill No. 10 is an 8-foot Ideal. The tower is made of wood, the axis of wheel being 30 feet above the ground. The wheel has 15 curved fans, each 31x19x7 inches, set at an angle of 29½ deg. with plane of wheel. It is back-geared 2½ to 1. The supply pipe is 1½ inches diameter; cylinder, 2½ inches diameter. The pump is of the common hand pump kind, with lift valve of the flap form and plunger of the lift variety. The valves leak some, as discharge is greater when pump is working rapidly than when working slowly. The supply pipe is on a well point 3 feet long and 1½ inches diameter, whose lower end is 50 feet below surface of ground. The lift was 33 feet, and the discharge per stroke ⅓ quart when pumping quite rapidly. The mean pressure was 26.94 inches and mean temperature 97 deg. F.

Mill No. 11 is a 12-foot Ideal. The tower is made of steel, the axis of wheel being 30 feet above the ground. The exposure is good and all the parts in good working order. The wheel has 21 curved fans, 31x19x7 inches, set at an angle of 29½ deg. to the plane of the wheel. It is back-geared 2½ to 1, and the wheel is held in the wind by a spring. The discharge pipe is 8 inches diameter; stroke, 12 inches. Supply pipe consists of two 3-inch pipes 14 feet long, each terminating in a 3-inch well point 3 feet long. The valves are both of the single flap variety. The water is 39½ feet below the surface of the ground. The lift, as nearly as could be ascertained, was 45 feet at the time of measurement: the discharge, 9 quarts per stroke. The water is pumped into a pond 60x40x6 feet. This plant has been in use about three years. The mean pressure was 26.91 inches, and the mean temperature 91 deg. F.

Mill No. 12 is a 14-foot Ideal. The tower is made of steel, 30 feet high to axis of wheel. The wheel has 24 curved fans, each 48¾x17½x8 inches, set at an angle of 30 deg. with plane of wheel. It is back-geared 2½ to 1. The pump is Frizell make. The discharge pipe is 10 inches diameter; cylinder, 9½ inches diameter; supply pipe, 6 inches diameter, terminating in a well point 10 feet long and 6 inches diameter, the lower end of which is 32 feet below the surface of ground. The lift, as nearly as could be estimated, was 11 feet. The discharge was 11.6 quarts per stroke. The mean pressure was 27.04 inches, and mean temperature 81 deg. F. The water is pumped into a reservoir 100x100x3 feet deep. The pump has been in use about one year.

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Mill No. 13 is a 12-foot Aermotor. The tower is made of wood; axis of wheel 25 feet above the ground. The exposure was good and plant in good working condition, having been in use about one year. The wheel is the same as that of mill No. 3. The pump is Stone make; discharge pipe, 10 inches diameter; supply pipe, 5 inches diameter, on well point 10 feet long, the lower end of which is 17 feet below the surface of ground. Length of stroke is 12 inches. The plunger valve is of the double flap and the check valve the single flap variety. The discharge per stroke at time of test was 14.4 quarts, and the lift about 11 feet. The mean pressure was 27.09 inches, and the mean temperature 91 deg. F. The important difference between this plant and No. 3 is, that the latter has a 4-inch supply pipe and an open well; the former a 5-inch supply pipe on a well point.

Mill No. 14 is a 12-foot Gem on a 60-foot steel tower. The pump is Gause make; cylinder, 8 inches diameter; length of stroke, 9 inches; supply pipe is in a 12-inch open well. The discharge per stroke was $9\frac{3}{4}$ quarts, and the lift $15\frac{1}{2}$ feet. The wind velocity was not measured for this mill.

Mill No. 15 is a 10-foot Gem. The tower is made of wood; the axis of wheel is 34 feet above the ground. The mill is in good working order, but the exposure is not good on account of trees. The wheel has 24 fans, each 36x11x$4\frac{3}{4}$ inches, set at an angle of 35 deg. with plane of wheel. It is back-geared 3 to 1. The pump is Stone's make; discharge pipe, 8 inches diameter; supply pipe, 3 inches diameter; stroke, 8 inches. The supply pipe is on a 3-inch well point, 8 feet long, whose lower end is $21\frac{1}{2}$ feet below surface of ground. The plunger valve is single flap form and the check lift. The depth to water is 10 feet. The discharge per stroke is 7 quarts; the lift about 15 feet. The mean pressure was 27.05 inches, and mean temperature 84 deg. F.

Mill No. 16 is a 10-foot Halliday, pumping water into the same pond as No. 15. The tower is wood; axis of wheel 28 feet above the ground. The wheel has 78 fans, each $36\frac{1}{4}$x4x$2\frac{1}{4}$ inches, set at an angle of $35\frac{1}{2}$ deg. to plane of wheel. It is not back-geared. The pump is Gause make, with discharge pipe 6 inches diameter; supply pipe, 4 inches diameter. There is a 6-inch galvanized iron pipe, forming an open well, extending 15 feet into the water. The depth to water is 11 feet, the lift 16 feet, and the discharge per stroke 3 quarts. The mean pressure was 27.02 inches, and the mean temperature 94 deg. F.

Mill No. 17 is a 12-foot improved Gem, on a 30-foot steel tower. The wheel has 32 curved fans, each 42x$11\frac{1}{2}$x$4\frac{3}{4}$ inches, set at an angle of 37 deg. with plane of wheel. It is back-geared 2 to 1. The pump is a Gause patent, with 8-inch discharge pipe, 4-inch supply pipe, and 12-inch stroke, in an open well formed of a 12-inch wooden casing. Depth to water, $17\frac{1}{4}$ feet; lift, $21\frac{3}{4}$ feet; discharge per stroke, $8\frac{3}{4}$ quarts. Mean pressure, 27.05 inches; mean temperature, 93 deg. F. This mill, although nearly new, does not work well; it is out of plumb. Only a few measurements of the number of strokes per mile of wind were made.

Mill No. 18 is an 8-foot Ideal, on a 36-foot wooden tower. The exposure was good, and all the parts in good working order. The wheel is like that of mill No. 4. The pump is Stone's make, with 6-inch discharge pipe -- no supply pipe -- the cylinder being under water, with $3\frac{1}{2}$-inch opening to it from below. The valves are lift variety for check, and single flap for plunger. The well is open, formed by a 10-inch galvanized pipe in the bottom of a part $4\frac{1}{3}$ feet in diameter and 8 feet deep. It is 11 feet to water. The lift is $14\frac{3}{4}$ feet; discharge per stroke, 2.92 quarts. The mean pressure was 27.01 inches; mean temperature, 85 deg. F. The cost of plant, including pond, was $125.

Mill No. 19 is a 12-foot Gem, on a 30-foot wooden tower. The exposure was good, and the mill in good working order. The wheel is like that of mill No. 17.

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The pump is Stone's make, with 10-inch discharge pipe, 4-inch supply pipe; length of stroke, 10 inches. The supply pipe is on a 4-inch well point 9 feet long, the end of which is 23 feet below the surface of ground. The check valve is lift form, and plunger single flap. The lift was about 18 feet; discharge per stroke, 12 quarts. Mean pressure, 27.13 inches; mean temperature, 70 deg. F. The water is pumped into reservoir 120x60 feet.

Mill No. 20 is a 15½-foot Jumbo. Its axis is a steel shaft, 8 feet above the ground; it has 6 fans each 9½x3½ feet; the outer radius is 7¾ feet, and the inner 4¼ feet. This mill works two pumps, one at each end of axis, each having a 6-inch cylinder, 3-inch discharge pipe, and 3-inch supply pipe on a well point 5 feet long, lower end 20 feet below surface of ground. The discharge of the two pumps was 10 quarts per stroke; the lift about 14 feet. The mean pressure was 27.09 inches; mean temperature, 85 deg. F. The anemometer was held 14½ feet above the surface of ground, or at the elevation of the center of a fan when in its highest position. The wheel is set in a large box extending up to a level with axis of wheel to prevent wind from striking wheel below its axis.

Mill No. 21 is a 12-foot Halliday, on a 31-foot wooden tower. The wheel has 64 fans each 42½x5x2⅜ inches, set at an angle of 35 deg. with the plane of wheel. It is not back-geared and regulates itself on the centrifugal principle by the fans taking the direction of the wind. The pump is Stone's make, with 7½-inch discharge pipe, 4-inch supply pipe, 7-inch stroke. The check valve is lift form, and the plunger double flap. The well is open, formed by a wooden curb 12 inches diameter, in the bottom of a dug well 9 feet deep. The depth to water was 11½ feet, and the lift 15 feet; the discharge per stroke was 4½ quarts when pumping quite rapidly (30 strokes per minute). The valves were not in very good repair, and the pump lost its priming after a time. Mean pressure was 27.00 inches; mean temperature, 71 deg. F.

Mill No. 25 is an 8-foot steel mill on a 32-foot steel tower, made by Fairbanks, Morse & Co. The wheel has 18 curved fans, each 29x11⅜x5¼ inches, set at an angle of 29 deg. with plane of wheel. It is back-geared 2½ to 1. The pump is of the common hand pump variety, 2½-inch cylinder, 1½-inch supply and discharge pipes, 4-inch stroke. The well is open, 6¼ feet to water, The discharge per stroke was .31 quart, and the lift 8½ feet. The water raised is used for watering stock.

RELATION BETWEEN NUMBER OF STROKES PER MILE OF WIND AND WIND VELOCITY IN MILES PER HOUR.

Figures 1 to 10 show graphically how the number of strokes of pump per mile of wind varies as the velocity increases. (Figure 1 of this synopsis shows this relation for mills No. 3 and 20.) The velocities are plotted as abscissa, and number of strokes as ordinates. This relation is found directly from the diagrams of the register. The pen connected with the anemometer makes say three short marks in 15 minutes, and the other pen registering hundred strokes makes say two short marks in the same time, then a mile is made in 5 minutes, the velocity is 12 miles per hour, and the pump makes 67 strokes in this mile. After as many of the points were plotted as thought necessary, a smooth curve was drawn among them, so as to have about as many on one side as on the other. This curve gave the measured relation. In order to determine the number of strokes more accurately than is possible by the diagram—since the distance between two of the short lines is small—the number of strokes to the mile of wind was counted and the time noted for quite a number of the plotted points. The curve for No. 20 is seen to be very different from any of the other curves. Leav-

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ing it out of account for the present, we see that while the others differ a good deal, they agree in that the curves rise rapidly, reaching a maximum at from 13 to 19 miles wind velocity, and then descend slowly. They differ much in the position of the beginning of the curve or the velocity required to start the mill; some will run in an 8-mile wind; others require a 10- or 12-mile wind to start them. Some rise less rapidly than others--especially No. 11. Some descend much more rapidly than others after reaching the highest point. This is especially true of the 8-foot Ideal. No. 12 required a 14-mile wind to start it, and does not appear to have a maximum.

Reasons for the Differences in the These Curves.

The shape of the curve, especially the position of its beginning point, is due to the load on the pump, or the number of foot pounds per stroke. Increasing the load moves the curves to the right and raises it higher. This will be shown more fully in discussion of power mill No. 27. The height of the highest point and its position depends on the tension of the spring or the weight which holds the mill in the wind. The greater the tension the higher the summit and the further it is to the right. No. 20 has no method of reducing the wind area and hence the curve has no summit. The less the tension in spring the steeper the descent from the highest point. The gearing — that is the mechanism for causing the pump to make a stroke to each revolution of wheel, or only a stroke every second or third revolution — modifies the curve. If working direct stroke the curve is much higher and is further to the right than if back-geared. Compare Nos. 3 and 21.

Columns 3 to 8, Table I, give the number of strokes per mile of wind for each mill for velocities of 8, 12, 16, 20, 25 and 30 miles per hour.

Number Strokes per Minute and Gallons per Hour.

Columns 9 to 14, Table I, give the number of strokes per minute for velocities of 8, 12, 16, 20, 25 and 30 miles per hour. These are found from columns 3 and 8, by dividing the number of strokes per mile by the number of minutes required to make the mile. Columns 15 to 21 give the number of gallons per hour that each pump was lifting in wind velocities of 8, 12, 16, 20, 25 and 30 miles per hour. These are found from columns 9 to 14 by multiplying the number of strokes per minute by 60 and this by the number of gallons per stroke.

Useful Work in Horse-Power.

The useful work in horse-power each mill is doing is given in columns 21 to 26 of Table I for wind velocities of 8, 12, 16, 20, 25 and 30 miles per hour. It is found from the numbers in columns 9 to 14 by multiplying these by q = the number of gallons per stroke, g = the weight per gallon, h = the lift, and dividing by 33,000, the number of foot pounds per horse-power, or we have the formula:

$$\text{H. P.} = \frac{n\,q\,g\,h}{33{,}000}$$

RELATION BETWEEN WIND VELOCITY AND HORSE-POWER IS SHOWN GRAPHICALLY FOR FIVE 12-FOOT MILLS IN FIGURE 2.

Column 27, table I, gives the vane area of the mills tested, and column 29 the pump load, or the number of foot pounds per stroke of pump. Examining the five curves of figure 2, we see that No. 11, the one which has the greatest horse-power, has the heaviest load, and requires the greatest wind velocity to start it. No. 2 has about five-eighths the load of No. 11, does less work, and requires about the same wind velocity to start the pump. No. 3 has a lighter load than

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No. 2, and will start in a wind of about 7 miles per hour. No. 19 has a little heavier load than No. 3, and does much less work at all velocities; the latter requires a 9- to 10-mile wind, while the former will start in a 7- to 8-mile wind. No. 21 is doing the least work of the five, and requires about an 11-mile wind to start it. It is a wooden mill making direct stroke, while the others are steel mills and back-geared. It must be understood in this comparison that no correction or allowance is made for difference in temperature and barometric pressure, nor for the fact that in Nos. 11 and 19 the pumps are on well points, while in the others they are in open wells.

Pumping for Stock and for Irrigation.

Mill No. 25 is used to pump water for stock. Comparing it with, say No. 5, we see that its load is about five-ninths and it is doing about one-tenth as much work as the latter. It will start with a wind velocity of about six miles per hour, while the latter requires a velocity of about 8½ miles.

Pump Load Due to Well Point.

On examining well points that have been used for a time, it is seen that many of the little openings through which the water passes into the pump have become filled with fine grains of sand, thus reducing the area through which the water can enter the pump. If this area was of the proper amount when the point was new, then it has become too small after it has been used for a time, or after it has stood in the ground for a time without being used. If this area is too small to allow free flow into pump, an added load is put on the pump. To measure the mean pull of the pump an instrument was devised by Mr. R. G. Stone, of Garden City, consisting essentially of a spiral spring, whose compression was proportional to the pull, and a pencil which moved up and down over a smooth surface. The spring was calibrated, and the pull in the pump rods of four of the pumps measured with it. The four pumps selected were operated by the same size and make of mill, and the pumps were the same except as to size of supply pipe, valves, and kind of well. The discharge was practically the same, but the lifts differed slightly. These were Nos. 3, 7, 13, and 22. Table II gives the pull in each case, after reducing to a common lift of 17 feet.

TABLE II.

Mill No.	Lift.	Kind of well.	Mean pull.
3	13¾ ft.	Open.	597 lbs.
7	17 "	Open.	734 "
13	12 "	4-inch well point.	944 "
22	13½ "	5-inch "	819 "

The straining capacity of No. 17 is not as great as that of No. 3, and the resistance of the valves is greater in No. 7 than No. 3.

The useful work two mills of the same wind area, exposure, etc., will do depends on the magnitude of the load on the mill and the wind velocity. If the mill is heavily loaded it will do more work in velocities of 12 or more miles per hour, and less in lower velocities than one of a lighter load. The useful work done in a given time is the product of the work done per hour at the mean velocity, and the number of hours during that time. If the mean velocity at a given place is low, the mill load must be less for maximum work than that at a place where the mean velocity is higher. To illustrate this fact we use the results of tests of two 12-foot pumping mills, No. 11 heavily loaded, and giving the

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greatest horse-power of any mill tested at high wind velocities, and No. 3, giving the greatest power at low velocities. The useful work per stroke of pump is 844 foot pounds for No. 11, and 415 foot pounds for No. 3. The useless work of the former is greater than that of the latter, since the pump is on two well points in the former, while the pump of the latter is in an open well.

The relation between horse-power and wind velocity for these mills is shown in the Fig. 2. The curves are seen to cross each other at a wind velocity of 12½ miles per hour. For less velocities than this No. 3 is doing more work per hour than No. 11, and for greater velocities No. 11 is doing more work than No. 3. If the velocity at this place were, say not more than 13 miles per hour, it is very evident that mill No. 3 would do more work in any time than No. 11.

There is no record of wind movement at this place (Garden City) for any considerable length of time. There is one for Dodge City, however, 50 miles east of Garden City, kept by the United States Weather Bureau, which may be used for this purpose. Table III gives the mean number hours per month for the six months, April to September inclusive, for the seven years 1889 to 1895 inclusive, that the wind movement was 0 to 5, 6 to 10, 11 to 15, 16 to 20, 21 to 25, 26 to 30, 31 and upwards miles per hour.

TABLE III. Seven-year means — 1889 to 1895, inclusive.

Months.	0-5.	6-10.	11-15.	16-20.	21-25.	26-30.	31 and upwards.
April	116	175	157	113	76	43	40
May	116	195	168	120	74	39	32
June	120	187	139	111	86	49	28
July	144	218	176	117	57	23	9
August	178	230	152	99	62	18	5
September	166	182	152	93	75	34	18
Sums	840	1,187	944	653	430	206	132
Means	140	198	157	109	72	34	22

It is seen from this table that the wind velocity is five miles or less per hour for 140 hours per month at this place. During this time neither of these mills will do any work, as neither will start in a five-mile wind. The velocity is from 6 to 10 miles per hour for 198 hours per month. Mill No. 3 will start in about a seven-mile wind and hence will run about ⅘ of this time, or 158 hours. No. 11 requires 11½ miles to start it and will do no work during this time. The velocity is 11 to 15 miles per hour for 157 hours during the month. No. 3 will work all the time and No. 11 about $\frac{9}{10}$, or 141 hours. Both mills are running for all higher velocities. Mill No. 3 will run (if in the wind) about 75 per cent. of the time at this place and No. 11 about 51 per cent. of the time.

TABLE IV.

Velocities.	Mill No. 3.			Mill No. 11.		
	Hours.	Power.	Product.	Hours.	Power.	Product.
6-10	158	.067	10.6	0	.00	0
11-15	157	.168	26.4	140	.19	26.8
16-20	109	.230	25.1	109	.40	43.6
21-25	72	.277	19.9	72	.56	40.3
26-30	34	.308	10.5	34	.63	21.4
31 and upwards	22	.320	7.0	22	.64	14.1
Totals			99.5			146.2

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TABLE I.

Mill No.	Name.	Size	Number of strokes per mile of wind when velocity is — miles per hour.						Number of strokes per minute when velocity is — miles per hour.					
			8	12	16	20	25	30	8	12	16	20	25	30
2	I. L. Diesem (Woodmansee Mogul)	12 ft.	....	28	60	61	56	51	....	5.2	16.0	20.3	23.3	25.3
3	—— Carless (Aermotor)	12 ft.	40	60	62	60	56	50	5.3	12.0	16.4	19.8	23.1	25.0
4	E. S. Austin (Ideal)	8 ft.	....	52	73	76	68	50	....	10.2	19.3	25.3	28.1	25.0
5	Ella Horner (Aermotor)	8 ft.	....	93	94	90	83	77	....	18.6	25.1	29.8	34.6	38.5
6	W. J. James (Gem)	8 ft.	....	62	67	66	61	58	....	12.4	17.9	22.0	25.4	28.5
7	O. V. Folsom (Aermotor)	12 ft.	....	57	59	57	53	47	....	11.4	15.8	19.0	22.1	23.5
8	J. C. Kitchen (Star)	10 ft.	210	150	.....	.....	.....	.....	28.0	30.0	.....	.....	.....	.....
9	F. M. Dunn (Aermotor)	16 ft.	....	53	53	52	47	42	....	10.6	14.1	17.2	19.6	21.0
10	F. M. Dunn (Ideal)	8 ft.	106	125	125	.....	.....	.....	14.1	25.0	33.3	.....	.....	.....
11	F. M. Dunn (Ideal)	12 ft.	....	24	48	57	56	50	....	4.8	12.7	18.8	23.3	25.0
12	D. M. Frost (Ideal)	14 ft.	23	55	59	58	52	....	3.1	10.9	15.7	19.2	21.5	....
13	Wm. Coulters (Aermotor)	12 ft.	....	55	64	63	59	55	....	11.0	17.1	21.0	24.6	27.5
15	Jas. Allen (Gem)	10 ft.	....	39	45	44	35	....	....	7.8	11.9	14.7	14.6	....
16	Jas. Allen (Halliday)	10 ft.	30	113	127	128	126	....	4.0	22.6	33.9	42.7	52.5	....
17	D. R. Menke (Gem)	12 ft.	....	30	48	52	.....	.....	....	6.0	12.8	17.3	.....	.....
18	Fred. Pile (Ideal)	8 ft.	60	101	114 / 98	102 / 84	79 / 66	..	8.0	20.2	26.1	28.0	27.5	....
19	W. E. Trell (Gem)	12 ft.	....	31	45	44	38	....	....	6.2	11.9	14.7	16.0	....
20	W. T. Cowhick (Jumbo)	15½	....	....	20	32	42	....	....	....	5.3	10.7	17.5	....
21	J. E. Hunt (Halliday)	12 ft.	....	70	107	112	107	....	....	14.0	28.5	37.3	44.6	....
22	Wm. Brown (Fairbanks)	8 ft.	92	146	140	114	80	....	12.3	29.2	37.3	38.0	33.3	....

TABLE I—Concluded.

Mill No.	Number gallons pumped per hour when wind velocity is — miles per hour.						Useful work in horse-power when wind velocity is — miles per hour.						Foot lbs. useful work per stroke of pump	Vane area in square feet	Lift (feet)	Size of pump*
	8	12	16	20	25	30	8	12	16	20	25	30				
2	.....	1,131	3,480	4,415	5,069	5,503	.....	.085	.260	.322	.379	.411	536.2	69.4	17.75	9½x12
3	1,153	2,610	3,567	4,306	5,014	5,437	.067	.151	.207	.250	.291	.315	415.3	72.9	13.75	9½x12
4	.....	306	579	759	843	750	.....	.015	.029	.038	.043	.038	50.0	36.1	12	5½x8
5	.....	977	1,318	1,564	1,817	2,021	.....	.053	.072	.086	.099	.111	94.9	33.7	13	6x8
6	.....	725	1,047	1,287	1,486	1,667	.....	.029	.042	.051	.059	.065	77.6	36.9	9.60	6½x8
7	.....	2,445	3,387	4,075	4,740	5,041	.....	.160	.221	.266	.309	.329	461.9	72.8	15.50	9½x12
8	101	108	.....	.....	.....	.....	.013	.014	.....	.....	.....	.....	15.0	59.8	30	3x5
9	.....	1,749	2,326	2,838	3,234	3,465	.....	.325	.433	.448	.601	.644	1,013.3	133.6	44.25	8x16
10	70	125	167	.....	.....	.....	.010	.017	.023	.032	.....	.....	22.8	42.0	33	2½x6
11	.....	648	1,714	2,538	3,150	3,375	.....	.123	.325	.481	.600	.639	843.7	75.3	45	7½x12
12	535	1,880	2,708	3,312	3,709	.....	.025	.087	.125	.153	.172	.....	263.5	103.6	11	9½x12
13	.....	2,376	3,694	4,536	5,314	5,940	.....	.110	.171	.210	.247	.275	330.0	72.8	11	10x12
15	.....	819	1,250	1,543	1,533	.....	.....	.053	.082	.101	.099	.....	219.0	47.3	15	7x8
16	180	1,017	1,526	1,922	2,362	.....	.012	.067	.103	.130	.159	.....	100.0	61.3	16	6x8
17	.....	765	1,632	2,206	.....	.....	.....	.070	.149	.202	.....	.....	385.0	75.8	21.75	8x12
18	348	879	1,135	1,218	1,196	.....	.022	.054	(.082) .070	(.092) .076	(.088) .074	.....	89.2	42.0	14.75	5½x8
19	.....	1,116	2,142	2,646	2,880	.....	.....	.085	.162	.201	.219	.....	450.0	77.6	18	10x10
20	.....	.....	795	1,605	2,625	.....	.....	.....	.047	.095	.154	.....	291.2	73.6	14	Two. 6x12
21	.....	945	1,924	2,518	3,010	.....	.....	.060	.121	.159	.184	.....	141.5	69.7	15	7½x7
22	57	136	173	177	155	.....	.002	.005	.007	.008	.005	.....	5.5	30.2	8½	2½x4

*Inside diameter of cylinder by length of stroke.

Columns 2 and 5, table IV, give the number hours during the month that each mill was running with wind velocity 6 to 10, etc., miles per hour. Columns 3 and 6 give the horse-power for the mean velocity. For example, .168 is the horse-power for No. 3 at 13 miles per hour, and .19 is the horse-power for No. 11 for the same velocity. Columns 4 and 7 give the product of the number hours and horse-power. The sums of these products give the horse-power that each mill is yielding during the month. It is seen that No. 11 is doing 31 per cent. more useful work than No. 3.

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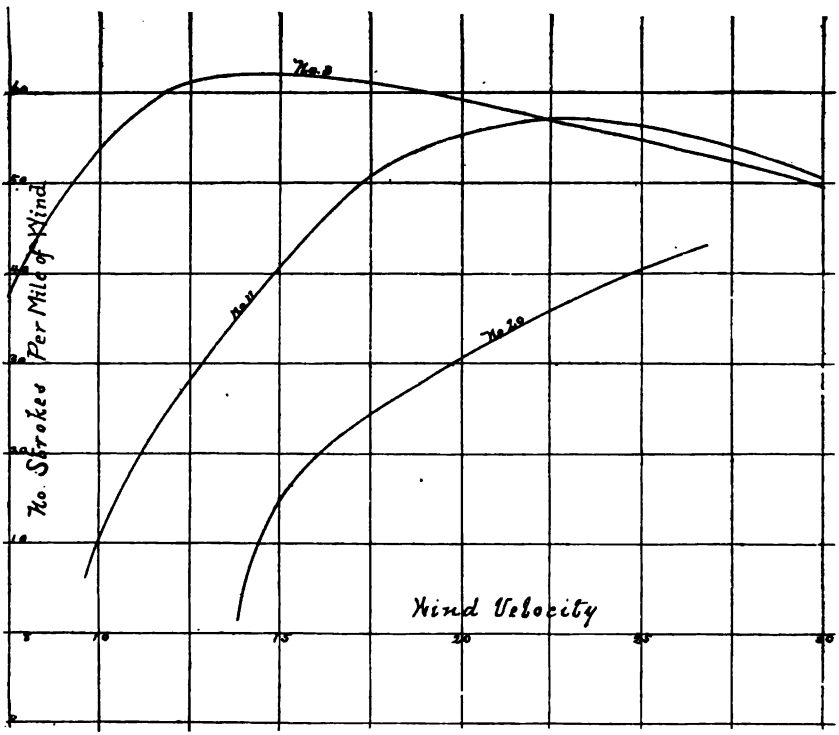

Fig. 1.

Showing relation between number of strokes of pump per mile of wind and wind velocity, for mills Nos. 3, 11, and 20.

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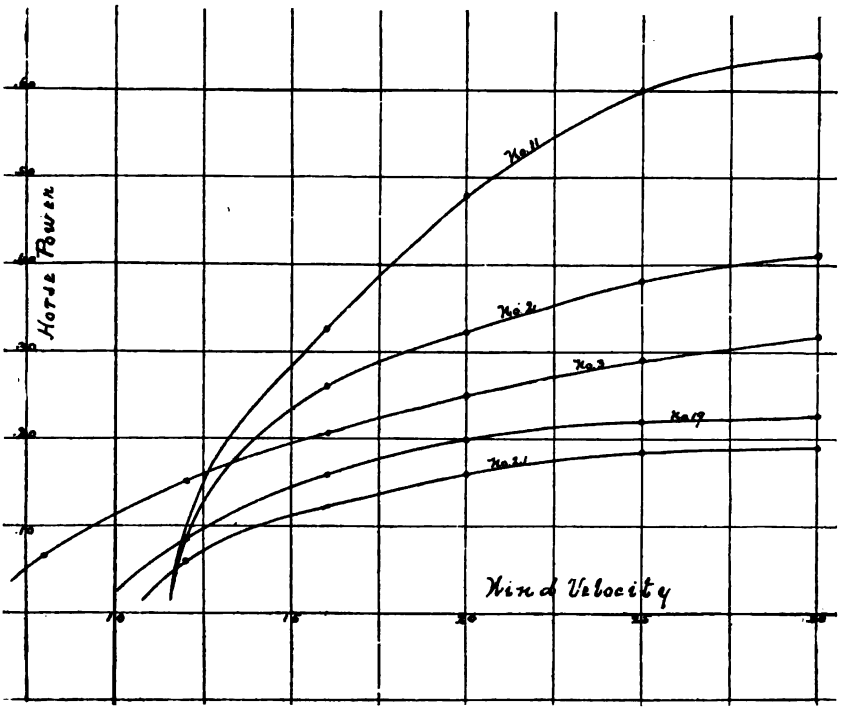

Fig. 2.

Showing relation between horse-power and wind velocity, for mills Nos. 2, 3, 11, 19, and 21.

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Power.

By M. B. TOMBLIN.

Only within the past few years has the water supply for irrigation purposes in this country been derived from any other source than diversion from streams or reservoirs by gravity.

While the people of Egypt, India and China have for several centuries employed some form of power for lifting water for irrigation purposes, and have brought under successful cultivation several millions of acres of arid land, yet the primitive methods employed by these people have not until recently seemed to offer any lesson that could be profitably studied by the western irrigator.

In the United States, throughout the arid and semiarid regions, isolated pumping plants for irrigation purposes have been successfully operated by individual irrigators, but in our own state not until within the past few years. From the success of the farmers along the Arkansas river, particularly in the vicinity of Garden City, has attention been directed to the fact that irrigation was practicable to a greater or less extent throughout a large portion of the state.

The fact that a very large portion of the waters available for irrigation purposes in this state lie where their diversion by gravity is not practicable, makes the problem of their successful utilization simply a matter of power.

Section 5 of the act under which this Board was created confined its investigations almost entirely to the uplands, and the actual experience of the Board has been, therefore, limited to deep-well pumping. In this field there was no precedent to follow. While a few deep wells, affording considerable quantities of water, had been sunk in various parts of western Kansas by the several railroad companies whose lines cross the state, they were so isolated and the demand made on these wells so different from that of a well used to supply water for irrigation purposes, that but little information of value could be derived from them.

In considering the question of power best adapted for lifting water for irrigation purposes on the uplands, the Board has only considered the question as it affects the individual plant, leaving for further investigation the problem of the successful application of water to larger areas.

STEAM.

In the consideration of steam as a motive power for operating pumps in deep wells, the investigations of the Board were not pursued very far until it became apparent that a steam pumping plant for the small irrigator on the uplands could not, under the conditions surrounding the farmers of western Kansas, be operated at a profit.

From reliable information furnished by the Santa Fe and Rock Island railroad companies, and from the engineers operating various city waterworks (notably that at Goodland), the average cost of raising water by steam runs from 5 to 10 cents per thousand gallons, varying according to the height of the lift. The average on the Santa Fe being much lower for the reason

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that their lines, where the greatest quantities of water are used, follow the valley of the Arkansas river, and consequently a very low lift is secured. The Rock Island, whose lines follow along the divide and higher lands of western Kansas and who are consequently obliged to secure their water from greater depths, shows a corresponding increase in cost of water.

The report of the engineer of the city water-works at Goodland was selected for the reason that at this point is located the largest deep-well pumping station in western Kansas, and from the fact that the plant is operated only for the purpose of supplying water for the city; the facilities are the best for obtaining, under favorable conditions, the closest figures as to cost of pumping.

The cost per 1,000 gallons at Goodland is about 5 cents, or $16.30 per acre foot. The pump would supply, if operated 365 days of 10 hours each, about 91 acre feet a year. The water lift here is in the neighborhood of 200 feet, including lift into tank, and it is fair to assume that the same power, with larger pumps, would at 100 feet elevate twice the amount of water at about the same cost, thereby reducing the cost per acre foot to $8.15, and supplying in a year 182 acre feet of water. The reverse would not be true, that with half the water lift, the same pumps would lift the same amount of water for half the cost, for the element of operating expenses, outside of fuel, would be about the same in each case, and this factor seems to make prohibitive the use of steam in lifting water on the uplands for irrigation purposes for the small farmer. This calculation did not take into consideration interest on the cost of the plant. In this instance, $3,000 would be a fair figure to consider as the cost of plant equipped to do this work. On low lifts, where large quantities of water are to be used, steam can be profitably employed, but on the uplands, for irrigation purposes, there is little reason to believe its use will become general, outside of specially valuable crops.

GASOLINE.

In considering this power the Board found an unexplored field, and so far as could be learned no deep-well pumps of large capacity were in operation. A contract was let to Fairbanks, Morse & Co., of Kansas City, for a gasoline pumping plant to be erected at Sherman county station No. 4. A cut of this plant may be seen on page —. It operates a 6-inch Cook pump in a 166-foot tubular well, with a water lift of 133 feet. As will be seen by report of W. G. Russell, C. E., *ante*, this engine pumped 787,600 gallons in 208 hours, using 265 gallons of gasoline. With gasoline at 13½ cents per gallon, the cost per acre foot is about $15.20.

After making these tests the engine was removed to Logan county station No. 5, at Oakley, where the lift was about 100 feet. Here a larger pump was to be operated and it was hoped better results could be obtained. In 415 hours the pump lifted 1,007,025 gallons, using 388.62 gallons of gasoline. This, with gasoline at 13½ cents per gallon, would make the cost about $14 per acre foot. In calculating the cost of water at Goodland and Oakley, it will be observed that freight on gasoline from Kansas City, oil, waste, and repairs, and salary of engineer, were not taken into consideration. These items would add very materially to the cost and would vary in every locality according to circumstances. The claims of the manufacturers that gasoline engines require no attention are to be taken with many grains of allowance when applied to deep-well pumping plants.

Why the cost for lifting water at Oakley should not show a wider differ-

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ence from that at Goodland is not clear, but we suspect was due to greater efficiency of the pump at Goodland, owing to the fact that the strainer through which the water passed into the pump was located in very coarse gravel, while at Oakley the conditions were not so favorable.

Owing to the unsatisfactory working of the machinery, these tests were not as favorable as they might have been, and in our opinion gasoline engines, under more favorable conditions, would show a somewhat lower cost.

WINDMILLS.

In the consideration of this power the Board found a more promising field for investigation. Already the pioneer irrigators of the state were, on the lower lands, successfully employing the windmill in raising water for irrigation purposes. On the uplands the farm windmill, after doing duty in supplying water for domestic and stock purposes, in many instances pumped the water to irrigate a small garden or a few trees.

When the Board commenced its investigations there were but very few large irrigating plants on the uplands. They had been constructed but a short time and their machinery had not been tested, and whether strong enough to withstand the heavy demands of deep-well pumping remained to be determined. The experience of the pioneer irrigators had demonstrated that the ordinary farm windmill was not strong enough to meet the demands of irrigation pumping, and already the leading manufacturers were in the field with heavier-constructed mills built expressly for this work. The Board purchased of the leading manufacturers or their agents, six different patterns of mills. Most of these mills were of recent design, built especially for irrigation work, and had not at this time reached the stage of perfection attained by the old farm mill on the work for which it was designed. These heavier mills require much more attention, and neglect occasions much more serious consequences. They are built to work in high wind velocities, and consequently at times are required to do many times the work required of them ordinarily. At such times the breaking of a bolt or a casting is almost certain to result in a wreck, more or less serious.

To safely utilize a high wind velocity and to ascertain the best proportion between power and pump are problems which when solved will add a very large per cent. to the efficiency of both mill and pump. The manufacturers are studying the question, but principally at the expense of the farmer who owns the mill or pump.

The reports of Professors Hood and Murphy clearly indicate the necessity of further scientific investigation.

Referring to Table I, page —, Professor Murphy's report, well No. 9 has a water lift of 44.25 feet, the pump cylinder, 8-inch, operated on a 16-inch stroke, the power a 16-foot steel back-geared wheel. Well No. 11 has a water lift of 45 feet, the pump cylinder 8 inches, operated on a 12-inch stroke, the power a 12-foot steel back-geared wheel.

It will be noted that the lifts in these wells are virtually the same; the cylinders are of the same diameter, but No. 11 uses a 16-inch stroke while No. 9 uses only a 12-inch stroke, the former pumping one-third more water at each stroke and requiring the same proportion of additional power to operate. No. 9 is operated by a 16-foot steel back-geared wheel and No. 11 by a 12-foot steel back-geared wheel. No. 9 is the old pattern farm mill, enlarged, and not intended to utilize high wind velocity. No. 11 is a mill built for irrigation work, and with heavy castings and machinery built to work

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in strong winds. Neither mill will work in an eight-mile wind; in a 12-mile wind the 16-foot wheel pumps 1,749 gallons and the 12-foot wheel 684 gallons per hour. In a 16-mile wind the 16-foot wheel pumps 2,326 gallons while the 12-foot wheel pumps 1,714 gallons. A 20-mile wind shows the 16-foot wheel lifting 2,838 gallons and the 12-foot 2,538 gallons. The 30-mile wind shows only a difference of 90 gallons per hour in the work of the mills.

If the 16-foot wheel had been constructed with sufficient strength, and so adjusted to have faced the same winds as the 12-foot wheel, there is no reason why the ratio of water lifted and power developed should not continue the same throughout the different wind velocities.

At station No. 4, Goodland, and station No. 9, Haskell, were employed wooden mills, both 25 feet in diameter, the one at Goodland being what is termed the solid wheel, and the one at Haskell open or sectional. These mills are termed railroad mills, and give good satisfaction. They are much more expensive, and the same-sized wheel develops much less power than the back-geared steel wheel. The manufacturers claim in their favor much greater durability, a claim which the Board is inclined to favor. Yet very much more power can be purchased for the same money by employing a steel back-geared wheel, and with the care and attention a mill should receive, we hardly think the increased cost compensates for the possibly greater durability.

In choosing a mill for irrigation purposes, one designed especially for this work should be selected, and of the latest improved pattern, the efficiency of which has been subjected to actual test. Improvements are constantly being made as actual work in the field demonstrates their necessity, and there is no reason to doubt that in the near future irrigation mills will be built able to utilize reasonably high wind velocities and at the same time govern and regulate themselves and require as little attention as should be given to the ordinary farm mill.

We give a table, showing size of wheel to employ in operating a cylinder of given diameter and capacity per stroke, lifting water from 5 to 200 feet, which will be found approximately correct.

TABLE showing relation between windmill and pump and capacities of cylinders.

Water lift.	10-foot back-geared.		12-foot back-geared.		14-foot back-geared.		16-foot back-geared.	
	Size of cylinder.	Gallons, 10-inch stroke.	Size of cylinder.	Gallons, 12-inch stroke.	Size of cylinder.	Gallons, 14-inch stroke.	Size of cylinder.	Gallons, 16-inch stroke.
5	13	5.7	17	11.8	22	19.6	25	34
10	8½	2.4	12	5.3	15	11	19	19.63
15	7½	1.8	10	4	13	8	15	12.24
20	7	1.6	8½	2.9	11	5.75	14	10.66
25	6	1.2	7½	2.3	10	4.76	12	7.83
35	5	.85	7	2	8½	3.43	10	5.44
50	4	.54	5½	.82	7	2.33	8½	3.93
75	3½	.41	4½	.82	5½	1.42	7	2.66
100	3	.3	4	.65	5	1.19	6	1.95
125	2¾	.25	3½	.5	4½	.96	5½	1.64
150	2½	.21	3¼	.44	4	.76	5	1.36
175	2¼	.17	3	.36	3¾	.66	4½	1.10
200	2	.12	2¾	.3	3½	.58	4	.87

These conclusions are based on the most reliable data available, and are confirmed by our experience with and observation of mills at work in various parts of the state, and sustained by the investigations of Professor Hood. It

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should be remembered that this table contemplates the use of modern built steel back-geared mills designed for irrigation work, and not the ordinary farm windmill. While undoubtedly some mills will operate larger pumps, it is believed that this table gives a proportion of power to pump that will prove generally satisfactory. As indicated by the report of the weather bureau at Dodge City, from records showing the average for the last 22 years, the average wind velocities during the months of March, April, May and June are something over 13 miles per hour. It is fair to assume that this high average is maintained by short periods of high velocities, which the farm windmill is not built to utilize. With a farm mill built to utilize high velocities, it is evident very much more favorable results will be obtained in the quantity of water lifted. The capacity per stroke, as given in the table, is computed on the longest stroke of the mill, as in all instances where the power is sufficient a pump should work on the longest stroke.

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Stream Measurements.

Very soon after the organization of the Board negotiations were opened with the United States Geological Survey for its cooperation in the work of measuring the water annually flowing in the streams west of the 98th meridian. Through correspondence with Prof. F. H. Newell and personal interviews between Mr. A. C. Davis and our Secretary an arrangement was effected for this work, by the terms of which the federal government was to put in and maintain at its own expense seven measuring stations, as follows:

At Beloit, for the measurement of the Solomon river.
At Beverly, for the measurement of the Saline river.
At Ellsworth, for the measurement of the Smoky Hill river.
At Hutchinson, for the measurement of the Arkansas river.
At Arkalon, for the measurement of the Cimarron river.
At Kiowa, for the measurement of the Medicine river.

Also to furnish all necessary implements and instruments, and employ skilled civil and hydrographic engineers to take charge of the stations, leaving the state board to employ and pay a man at each station to take the daily readings of the depth of the water, at an expense of $5 per month for each station.

It is estimated by competent authority that the part taken in this stream measurement by the United States government for the two years which the Board lasts, if undertaken by the state board on its own responsibility, would cost a very large proportion of its appropriation.

Duplicate reports of the observations at these stations are furnished to the United States government and to this Board.

The persons taking the daily readings are called observers, and have been paid by our Board at the rate of $5 per month each until November 1, 1896. Since which time United States Geological Survey has assumed the entire expense of the work. The total sum expended by this Board on account of this work is $541.51. These reports have been tabulated by Mr. W. G. Russell, civil and hydrographic engineer, who has general charge of the stations. His report to our Board is here given in full.

REPORT OF W. G. RUSSELL, C. E.

I herewith submit a report of the measurements of the flow of water in the Republican, Solomon, Saline, Smoky Hill, Arkansas, Cimarron and Medicine rivers, of which I had charge as hydrographer for the United States geological survey.

A gaging station is first established on each river, and a correct gage, graduated to feet and tenths, is put in the river and a reliable man secured at each station who reads and records the gage height twice each day, and at the end of each week copies of these readings are sent in, one to the Board of Irrigation and one to me. From these the computations of daily flow are made after a sufficient number of meter readings are taken to construct a rating table. As often as

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possible these stations were visited by me and measurements of volume of flow taken with a current meter, and a rating table was constructed from these for each station, from which the volume of discharge for each gage reading is taken.

The results are for a period of 18 months, beginning July 1, 1895, and ending December 31, 1896, except for the Cimarron and Medicine rivers, which end October 31, 1896, a period of 16 months. Each station on each river, except the Republican, was established as near the 98th meridian as possible, taking into account adaptability, access, etc., in order that results of measurements would cover the same territory in which the State Board of Irrigation was conducting its experiments.

JUNCTION CITY STATION, REPUBLICAN RIVER,

This station was established April 26, 1895, by Mr. Arthur P. Davis. It is located at the wagon bridge at the north end of Washington street, Junction City, Kas., and is near the junction of this river with the Smoky Hill, forming the Kansas river. The measurements therefore give the run-off of the Republican basin. The observer is John Davis, living near the station. The gage consists of two oak timbers 4x4 inches, one inclined, the other nearly vertical. The former is bolted to a post driven into the bed of the river and bolted and braced to a cottonwood tree; the vertical portion is spiked to the same tree.

The scale is painted on pine boards, firmly nailed to the oak timbers. The inclined scale is marked in tenths of a foot from 1 foot to 10 feet, and the vertical portion from 10 feet to 27 feet. The bench mark consists of a 60-penny nail driven into the base of the tree at an elevation of 10.67 feet on the scale.

A subsidiary gage has been placed 507 feet upstream. It consists of a vertical oak stick with a painted scale nailed to it and referred to the same datum as the lower gage.

The difference of these two readings gives the slope of the river for this distance.

The initial point for soundings is on the right bank at the end of the bridge. The channel above the station is straight for about 100 feet, and below the station for about 300 feet. The right bank is high and is not likely to overflow. The left bank is low and sandy and may be overflowed in high water. The bed of the stream, especially from the center to the left bank, is sandy and shifting.

The measurements of discharge and daily mean gage height and discharge in second feet are given in the following tables:

List of discharge measurements made on Republican river, at Junction City, Kas.

No.	Date.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (square feet).	Mean velocity (feet per second).	Discharge (second feet).	Remarks.
	1895.							
1..	Apr. 27	A. P. Davis.....	28	3.00	.....	1.52	219	Haskell meter.
2..	Aug. 20	W. G. Russell..	28	4.75	701	2.72	1,911	" "
3..	Oct. 11	A. P. Davis and W. G. Russell..	61	2.57	144	1.95	281	Price meter.
4..	Nov. 11	W. G. Russell...	28	2.60	147	1.95	286	Haskell meter.
5..	Dec. 13	" ...	28	2.95	187	2.02	378	" "
6..	" 27	" ..	28	3.18	187	2.38	447	" "
	1896.							
7..	Jan. 15	" ...	28	3.50	263	1.91	504	" "
8..	" 27	" ...	28	3.12	235	1.74	410	" "
9..	Feb. 10	" ...	28	3.70	321	2.32	745	" "
10..	Apr. 16	" ...	28	6.50	1,000	3.62	3,621	" "
11..	May 14	" ...	28	5.75	953	3.29	3,135	" "
12..	June 16	" ...	28	3.90	599	1.86	1,116	" "
13..	" 27	" ...	25	4.30	518	2.87	1,488	" "
14..	July 11	" ...	28	4.20	440	2.61	1,150	" "
15..	Aug. 12	" ...	28	3 55	389	2.22	866	" "
16..	" 28	" ...	55	4.00	428	2.63	1,126	Price "
17..	Sept. 19	" ...	55	4.90	515	3.31	1,705	" "
18..	" 30	" ...	55	2.80	147	2.64	388	" "
19..	Oct. 20	" ...	55	2.75	186	1.91	355	" "
20..	" 28	" ...	55	2.80	219	1.58	347	" "
21..	Nov. 17	" ...	55	3.30	268	2.22	594	" "
22..	Dec. 10	" ...	55	3.50	310	1.78	551	" "

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Daily mean gage height and discharge in second feet of the Republican river. Drainage area, 25,837 square miles.
Observer, JOHN DAVIS.

DAY.	July, 1895.		August, 1895.		September, 1895.		October, 1895.		November, 1895.		December, 1895.		January, 1896.		February, 1896.		March, 1896.		DAY.
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	
1	3.85	636	3.85	636	5.40	4,170	2.40	240	2.35	230	2.60	286	3.55	556	3.65	677	3.50	504	1
2	3.75	563	3.85	636	5.01	2,580	2.30	220	2.40	240	2.60	286	3.40	485	3.95	1,121	3.50	504	2
3	3.65	497	3.70	528	4.15	903	2.65	299	2.45	251	2.60	286	3.30	467	4.05	1,131	3.50	504	3
4	3.55	439	3.55	439	3.85	636	2.75	326	2.40	240	2.60	286	3.05	398	3.90	1,116	3.50	504	4
5	5.05	2,740	3.75	563	3.75	563	2.60	286	2.35	230	2.60	286	3.10	400	3.80	925	3.50	504	5
6	4.55	1,496	3.45	387	3.75	563	2.60	286	2.50	262	2.65	298	3.05	398	3.85	970	3.50	504	6
7	3.65	497	3.30	320	3.45	387	2.50	262	2.60	286	2.75	322	2.90	392	4.05	1,131	3.50	504	7
8	3.60	467	3.20	282	3.50	412	2.50	262	2.55	274	2.95	278	3.10	400	4.00	1,126	3.50	504	8
9	5.20	3,280	3.15	265	3.55	439	2.50	262	2.40	240	2.85	350	3.05	398	3.80	925	3.50	504	9
10	4.75	1,910	3.70	528	3.30	320	2.50	262	2.50	262	3.00	392	3.35	475	3.75	785	3.50	504	10
11	4.75	1,910	4.85	2,150	3.00	219	2.55	274	2.60	286	2.90	365	3.30	467	3.85	970	3.50	504	11
12	5.25	3,490	5.60	5,320	2.85	+355	2.50	262	2.50	262	2.85	350	3.30	467	3.80	925	3.50	504	12
13	5.20	3,280	5.50	4,720	2.80	340	2.50	262	2.60	286	2.85	350	3.35	475	3.75	785	3.50	504	13
14	4.50	1,450	4.90	2,280	2.75	320	2.50	262	2.60	286	2.95	378	3.30	467	3.70	745	3.50	504	14
15	4.25	1,037	4.55	1,496	2.70	312	2.50	262	2.60	286	2.90	365	3.35	475	3.65	677	3.50	504	15
16	4.05	802	6.65	18,000	2.55	274	2.50	262	2.60	286	2.90	365	3.50	504	3.60	612	3.50	504	16
17	3.95	719	7.25	25,000	2.60	286	2.40	240	2.70	312	3.05	406	3.30	467	3.60	612	3.50	504	17
18	5.20	3,280	5.65	5,560	2.55	274	2.40	240	2.70	312	3.00	392	3.20	450	3.60	612	3.50	504	18
19	5.30	3,710	5.85	7,200	2.45	251	2.30	220	2.60	286	3.05	406	3.10	400	3.55	556	3.50	504	19
20	5.35	3,940	4.55	1,496	2.45	251	2.30	220	2.70	312	3.40	518	3.05	398	3.55	556	3.50	504	20
21	5.70	6,000	4.05	802	2.35	230	2.30	220	2.80	340	3.55	575	3.05	398	3.55	556	3.50	504	21
22	5.45	4,440	3.75	563	2.50	262	2.30	220	2.85	355	3.45	536	3.20	450	3.60	612	3.50	504	22
23	5.00	2,580	3.75	563	2.45	251	2.30	220	2.80	340	3.40	518	3.40	485	3.60	612	3.50	504	23
24	4.60	1,587	3.85	636	2.30	220	2.30	220	2.60	286	3.45	536	3.30	467	3.55	556	3.50	504	24
25	4.40	1,244	3.70	528	2.40	240	2.35	230	2.60	286	3.55	575	3.20	450	3.55	556	3.50	504	25
26	4.15	908	3.65	497	2.35	230	2.30	220	2.70	312	3.40	518	3.15	425	3.50	504	3.50	504	26
27	4.00	763	3.45	387	2.35	230	2.35	230	2.70	312	3.20	451	3.05	398	3.55	556	3.50	504	27
28	3.85	636	3.40	363	2.45	251	2.40	240	2.55	274	3.20	451	3.20	450	3.50	504	3.50	504	28
29	3.75	563	3.65	497	2.45	251	2.40	240	2.50	262	3.10	421	3.30	467	3.50	504	3.50	504	29
30	3.70	528	6.05	9,100	2.40	240	2.40	240	2.50	262	2.60	286	3.40	485	.....	.....	3.50	504	30
31	3.60	467	5.85	7,200	.....	.....	2.40	240	.....	.....	2.35	230	3.40	485	.....	.....	3.50	504	31
Totals	.....	55,814	.....	98,942	.....	16,265	.....	7,729	.....	8,458	.....	12,163	.....	13,899	.....	21,917	.....	15,624	.....
Mean		1,800		3,192		542+		249		282—		392		448.4		755.7		504	.....
Run-off, in inches		.09+		.16		.026		.012		.013		.019+		.020		.031		.022	.....
Run-off, per sq. mile		.08—		.14—		.023		.011		.012		.017		.017+		.029		.019	.....

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Daily mean gage height and discharge in second feet of the Republican river. Drainage area, 25,837 square miles.
Observer, JOHN DAVIS.

DAY.	April, 1896.		May, 1896.		June, 1896.		July, 1896.		August, 1896.		September, 1896.		October, 1896.		November, 1896.		December, 1896.		DAY.
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	
1	3.50	504	4.45	1,320	4.90	1,705	3.55	773	4.00	1,126	3.10	500	2.80	388	4.65	1,480	3.70	904	1
2	3.50	504	4.30	1,217	6.30	3,510	3.35	627	3.80	1,004	3.00	459	2.80	388	4.25	1,180	3.85	1,060	2
3	3.50	504	4.25	1,180	7.20	3,980	3.30	594	3.60	814	2.95	440	2.80	388	3.90	1,116	3.80	1,004	3
4	3.50	504	5.25	2,180	6.20	3,450	3.40	660	3.45	693	2.85	405	2.75	372	3.55	773	3.75	954	4
5	3.50	504	5.95	3,305	6.20	3,450	3.35	627	3.60	814	2.80	388	2.80	388	3.40	660	3.95	1,121	5
6	3.50	504	6.20	3,450	4.95	1,765	6.10	3,390	3.60	814	2.80	388	2.75	372	3.30	594	3.80	1,004	6
7	3.50	504	6.45	3,595	4.95	1,765	5.80	3,240	3.45	695	2.70	356	2.70	356	3.20	544	3.60	814	7
8	3.50	504	6.45	3,595	4.55	1,400	5.70	3,025	3.35	627	2.65	341	2.70	356	3.10	500	3.50	733	8
9	3.65	677	5.10	1,980	4.65	1,480	5.40	2,425	3.25	569	2.60	326	2.70	356	3.10	500	3.50	733	9
10	3.45	494	4.50	1,362	4.55	1,400	5.00	1,830	3.15	522	2.75	372	2.70	356	3.10	500	3.50	733	10
11	3.40	485	4.20	1,150	4.30	1,217	4.85	1,655	3.00	459	2.75	372	2.70	356	3.20	544	3.50	733	11
12	3.50	504	4.10	1,137	4.15	1,143	4.95	1,765	3.55	773	2.60	326	2.70	356	3.20	544	3.50	733	12
13	3.45	494	4.40	1,287	3.95	1,121	4.85	1,655	3.70	904	2.60	326	2.75	372	3.20	544	3.50	733	13
14	3.50	504	5.40	2,425	3.85	970	4.55	1,400	3.65	859	5.00	1,830	2.80	388	3.20	544	3.55	773	14
15	4.90	1,705	5.70	3,025	3.85	970	4.40	1,287	3.20	544	3.65	859	2.80	388	3.20	544	3.60	814	15
16	6.50	3,621	5.90	3,280	3.85	970	4.20	1,150	3.00	459	3.50	733	2.80	388	3.30	594	3.60	814	16
17	6.75	3,770	5.60	2,810	3.75	785	4.20	1,150	3.00	459	3.70	904	2.70	356	3.30	594	3.65	859	17
18	5.65	2,910	5.00	1,830	3.60	612	10.85	37,500	3.00	459	3.75	954	2.70	356	3.30	594	3.50	733	18
19	5.10	1,980	6.80	3,621	3.55	556	8.80	31,500	3.20	544	4.70	1,523	2.75	372	3.35	624	3.30	594	19
20	4.55	1,400	7.00	3,920	3.45	494	6.50	3,621	4.50	1,362	5.40	2,425	2.70	356	3.35	624	3.45	680	20
21	4.25	1,182	6.10	3,390	3.70	745	5.15	2,030	4.95	1,765	4.35	1,252	2.70	356	3.30	594	3.50	733	21
22	4.10	1,137	5.30	2,280	3.55	556	5.65	2,910	5.35	2,340	3.65	859	2.70	356	3.25	569	3.60	814	22
23	4.10	1,137	4.75	1,565	3.55	556	5.10	1,980	4.70	1,523	3.35	627	2.70	356	3.05	479	3.80	1,004	23
24	6.20	3,450	4.40	1,287	3.85	970	4.35	1,252	4.35	1,252	3.15	522	2.70	356	3.10	500	3.70	904	24
25	5.90	3,280	4.25	1,180	4.05	1,131	4.10	1,137	4.05	1,131	3.05	479	2.70	356	3.00	459	3.50	733	25
26	5.30	2,280	4.05	1,131	3.65	677	3.80	1,004	3.90	1,116	3.00	459	2.70	356	3.50	733	3.50	733	26
27	5.40	2,425	3.85	970	4.15	1,143	3.65	859	3.75	954	2.90	422	2.75	372	3.50	733	3.50	733	27
28	4.95	1,765	3.80	925	3.90	1,116	3.60	814	3.95	1,121	2.80	388	2.80	388	3.40	660	3.50	733	28
29	4.75	1,565	3.75	785	3.85	970	3.55	773	3.55	773	2.80	388	3.00	459	3.30	594	3.50	733	29
30	4.85	1,650	4.05	1,131	3.45	494	3.45	695	3.35	627	2.80	388	4.05	1,480	3.50	733	3.50	733	30
31			6.40	3,570			3.45	695	3.25	569			5.25	2,180			3.50	733	31
Totals		42,407		65,843		41,101		114,003		27,673		20,011		14,723		19,051		25,122	
Mean	1,413.6		2,124		1,370		3,677.5		892.7		667+		475−		655		810.4		
Run-off, in inches	.061+		.095		.059		.162		.039		.028		.021		.027		.036		
Run-off, per sq. mile	.055		.082		.053		.139		.034		.024		.018		.023		.031		

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BELOIT STATION, ON SOLOMON RIVER.

This station was established April 22, 1895, by Mr. Arthur P. Davis, at the wagon bridge on the south edge of the town of Beloit, Kas.

The first gage was an inclined oak timber bolted to a post and to a buried log, marked from 2 feet to 5.3 feet, the scale being continued on the iron bridge pier. This timber gage having been carried away by high water, a new gage was constructed by me and spiked to the floor of the bridge in a horizontal position, and the reading is taken by a sash-weight attached to a small brass chain let down to the water surface, and the lower edge of a ring on the chain giving the proper gage reading. This gives good results and is very easy of construction and is always in sight and ready for use, no matter how high the water, unless over the bridge. The bench mark is a 10-penny nail driven into the base of a cottonwood tree 35 feet northwest of the pier upon which the marks are made. Its elevation, 13.70 feet. Discharge measurements are made from the from the bridge, the initial point being on the left bank at the south edge of the stone abutment.

The channel above and below is straight for about 200 feet. Both banks are high and not likely to overflow. The bed of the stream is gravelly, but has been changed considerably, during the year, by dredging. In the case of this stream, it is a matter of considerable difficulty to obtain accurate data for computations of the mean daily discharge, as there are a large number of mills located along the stream, each of which backs up the water for a considerable distance and holding the water until a sufficient amount accumulates to overflow. During the day the mills run irregularly, sometimes with one wheel or more, and thus rapid fluctuations occur. Readings are taken twice each day, and it is assumed that by averaging these the errors through a month or season will balance each other, and fairly represent the height of water, from which the discharge can be estimated.

The following tables give the discharge measurements and the daily gage heights and daily discharge measurements:

List of discharge measurements made on Solomon river, at Beloit, Kas.

No.	Date.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (square feet).	Mean velocity (feet per second).	Discharge (second feet).	Remarks.
	1895.							
1	Apr. 20	A. P. Davis	28	2.90	.....	1.60	148	Haskell meter.
2	Aug. 19	W. G. Russell	28	3.27	119	1.64	195	" "
3	Oct. 31	"	3	2.10	24.6	.33	8	Price "
4	Nov. 1	"	3	2.93	63	1.24	78	" "
5	Dec. 13	"	28	2.85	91	1.19	109	Haskell "
6	" 27	"	28	2.80	98	1.07	105	" "
	1896.							
7	Jan. 14	"	28	1.90	.....	.....	5	Estimated.
8	" 14	"	28	2.75	104	1.01	115	Haskell meter.
9	" 31	"	28	2.65	102	1.22	125	" "
10	Feb. 12	"	28	2.75	109	1.13	123	" "
11	Apr. 17	"	28	4.58	325	2.26	734	" "
12	May 14	"	28	4.35	302	2.12	638	" "
13	June 5	"	28	4.80	338	1.95	756	" "
14	" 27	"	28	4.05	251	.83	209	" "
15	July 9	"	28	4.25	300	1.18	353	" "
16	Aug. 12	"	28	4.20	281	.93	261	" "
17	" 28	"	55	4.15	277	.79	220	Price "
18	Sept. 19	"	55	3.90	194	.69	135	" "
19	" 30	"	55	3.40	168	.53	88	" "
20	Oct. 20	"	55	3.10	143	.61	87	" "
21	" 28	"	55	3.00	138	.61—	84	" "
22	Nov. 17	"	55	3.00	181	.53	96—	" "
23	Dec. 11	"	55	3.10	169	.55	94	" "

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Daily mean gage height and discharge in second feet of the Solomon river. Drainage area, 5,539 square miles.
Observer, E. C. GROVER.

DAY.	July, 1895.		August, 1895.		September, 1895.		October, 1895.		November, 1895.		December, 1895.		January, 1896.		February, 1896.		March, 1896.		DAY.
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	
1	3.00	159	3.40	216	4.80	615	2.65	36	2.55	26	2.05	7	2.70	110	2.90	119	2.00	8	1
2	3.20	185	3.40	216	4.45	472	2.65	36	2.55	26	2.45	30	2.70	110	2.82	114	3.00	123	2
3	3.30	200	5.90	1,400	3.80	291	2.65	36	2.05	7	2.45	30	2.30	24	2.92	119	2.75	112	3
4	3.05	165	5.80	1,300	3.70	270	2.65	36	2.55	26	2.55	47	2.70	110	2.92	119	2.90	114	4
5	16.50	21,000	6.90	2,910	3.55	241	2.65	36	2.55	26	2.55	47	2.25	19	2.92	119	2.25	19	5
6	12.45	14,000	6.35	1,900	3.50	233	2.65	36	2.55	26	2.55	47	2.70	110	2.92	119	2.70	110	6
7	5.40	967	4.80	615	3.40	216	2.85	62	2.55	26	2.55	47	2.30	24	2.92	119	2.70	110	7
8	3.95	326	4.25	407	3.10	172	2.80	54	2.55	26	2.20	12	2.70	110	2.95	121	2.25	19	8
9	4.00	338	4.10	364	3.20	185	2.55	26	2.55	26	2.95	187	2.70	110	2.42	36	2.90	119	9
10	4.25	407	4.10	364	3.20	185	2.55	26	2.05	7	2.95	187	2.70	110	2.92	119	2.70	110	10
11	4.10	364	4.15	374	3.10	172	2.55	26	2.45	21	2.95	187	2.30	24	2.95	121	2.80	114	11
12	3.90	314	5.60	1,120	3.05	165	2.60	31	2.55	26	2.95	187	1.90	5	2.92	119	2.75	112	12
13	3.80	291	5.80	1,300	3.05	165	2.10	8	2.55	26	2.95	187	2.70	110	2.55	58	2.75	112	13
14	3.75	280	4.45	472	3.00	159	2.50	24	2.55	26	3.45	250	2.30	24	2.95	121	2.75	112	14
15	7.60	4,870	4.05	352	3.00	159	2.55	26	2.55	26	2.85	129	2.30	24	2.92	119	2.25	19	15
16	6.90	2,910	3.65	260	2.95	153	2.55	26	2.55	26	2.95	187	2.70	110	2.38	33	2.65	92	16
17	5.20	832	3.70	270	3.00	159	2.55	26	2.05	7	2.80	105	2.70	110	2.82	115	2.75	112	17
18	4.10	364	3.55	241	3.10	172	2.55	26	2.45	21	2.65	57	2.95	121	2.72	111	2.70	110	18
19	3.95	326	3.40	216	3.05	165	2.55	26	2.55	26	2.90	153	2.30	24	2.75	112	2.70	110	19
20	3.80	291	3.25	192	2.65	36	2.05	7	2.55	26	3.00	221	2.90	119	2.75	112	2.75	112	20
21	7.85	5,800	3.20	185	2.30	14	2.55	26	2.55	26	3.00	221	2.95	121	2.72	111	2.75	112	21
22	9.70	9,000	3.20	185	2.60	31	2.55	26	2.55	26	2.35	20	2.95	121	2.70	110	2.50	51	22
23	6.60	2,350	3.20	185	2.70	41	2.55	26	2.55	26	2.80	105	2.70	110	2.25	19	2.70	110	23
24	4.50	490	3.20	185	2.70	41	2.55	26	2.05	7	3.00	221	2.95	121	2.70	110	2.70	110	24
25	4.20	392	3.10	172	2.30	14	2.55	26	2.45	21	2.40	24	2.95	121	2.70	110	2.70	110	25
26	4.00	338	3.10	172	2.65	36	2.50	24	2.45	21	2.70	84	2.30	24	2.75	112	2.75	112	26
27	3.85	303	3.10	172	2.65	36	2.05	7	2.55	26	3.00	221	2.90	119	2.70	110	3.00	123	27
28	3.65	260	3.15	178	2.65	36	2.45	21	2.55	26	3.00	221	2.90	119	2.60	76	2.80	114	28
29	3.65	260	17.50	24,000	2.50	24	2.55	26	2.55	26	2.35	20	2.90	119	2.75	112	2.80	24	29
30	3.60	250	10.00	10,000	2.45	21	2.55	26	2.55	26	2.25	14	2.90	119	.....	.....	2.75	112	30
31	3.45	224	4.70	570	.....	.....	2.55	26	.....	.....	2.75	86	2.88	118	.....	.....	2.60	76	31
Totals	.....	68,256	.....	50,493	.....	4,679	.....	868	.....	684	.....	3,541	.....	2,720	.....	2,995	.....	2,903	.....
Mean		2,202—		1,629—		156		28		23—		114		87.7		103.3		93.6	
Run-off, in inches		.460+		.34+		.032—		.006—		.005—		.024		.018		.020		.019	
Run-off, per sq. mile		.400+		.29+		.028+		.005+		.004+		.021		.016		.018+		.017	

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Daily mean gage height and discharge in second feet of the Solomon river. Drainage area, 5,539 square miles.
Observer, E. C. GROVER.

Day.	April, 1896.		May, 1896.		June, 1896.		July, 1896.		August, 1896.		September, 1896.		October, 1896.		November, 1896.		December, 1896.		Day.
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	
1	2.70	110	4.05	209	6.35	1,950	4.55	777	4.95	803	3.75	118	3.20	87	3.30	117	3.10	94	1
2	2.35	29	4.20	261	9.50	8,740	4.25	361	4.75	751	3.30	87	3.30	88	2.90	75	3.00	84	2
3	2.35	29	3.80	124	7.20	3,630	4.50	697	4.45	677	3.50	96	3.20	87	2.70	60	3.10	94	3
4	2.40	35	3.65	108	5.90	1,400	4.40	657	4.05	209	3.40	88	2.40	20	2.90	75	3.10	94	4
5	2.30	24	3.65	108	4.85	760	4.80	756	3.95	157	3.40	88	3.10	87	2.85	71	3.10	94	5
6	2.75	112	3.55	100	4.75	751	6.80	2,720	3.85	129	2.55	28	2.60	29	2.90	75	2.80	38	6
7	2.80	114	3.50	96	4.90	765	6.00	1,507	4.10	214	2.75	32	3.00	84	3.00	84	3.10	94	7
8	2.75	112	3.80	80	5.55	1,130	4.50	697	4.60	738	3.40	88	2.95	84	2.20	34	3.10	94	8
9	2.60	76	3.20	72	4.65	722	4.25	361	4.35	565	2.85	40	3.15	87	3.00	84	3.10	94	9
10	2.60	76	3.20	72	4.25	361	4.15	236	4.20	261	3.40	88	3.05	84	3.00	84	3.10	94	10
11	2.00	8	3.40	88	4.15	236	5.20	938	4.00	180	3.45	92	2.15	10	3.05	89	3.10	94	11
12	4.85	760	3.25	76	4.10	214	4.70	747	4.15	236	3.40	88	2.80	33	3.00	84	3.30	117	12
13	15.75	18,500	3.30	80	4.05	197	4.25	361	4.00	180	2.85	40	2.65	30	3.00	84	2.65	57	13
14	11.60	12,000	4.60	738	3.80	124	4.00	180	3.70	113	3.75	118	2.65	30	3.00	84	3.30	117	14
15	11.90	12,800	4.80	756	3.85	129	3.85	129	3.60	104	5.25	960	2.60	29	2.20	34	3.25	111	15
16	5.80	1,300	4.70	747	3.60	104	3.65	108	3.65	108	4.05	196	3.20	87	3.05	89	3.35	124	16
17	4.50	697	7.55	4,700	3.80	124	3.85	129	3.45	92	3.75	118	3.15	87	3.00	84	3.05	89	17
18	4.35	565	4.40	657	3.80	124	4.05	209	3.70	113	3.95	157	2.50	28	3.00	84	3.15	99	18
19	4.20	261	4.30	475	4.20	261	3.95	157	3.65	108	4.00	180	2.75	32	3.05	89	3.10	94	19
20	4.60	738	5.40	1,046	4.60	738	3.95	157	3.90	135	4.15	232	3.05	84	3.10	94	2.50	48	20
21	4.20	261	4.80	756	4.15	236	3.90	135	4.55	717	3.95	157	2.65	30	2.70	60	3.15	99	21
22	3.90	135	4.25	361	4.00	180	4.60	738	4.35	565	3.70	113	3.05	84	2.40	43	3.15	99	22
23	3.70	113	4.00	180	4.05	209	4.05	209	4.40	657	3.60	104	3.05	84	3.10	94	3.20	105	23
24	3.70	113	3.80	124	3.75	118	4.05	209	4.55	717	3.85	130	2.80	38	3.10	94	3.20	105	24
25	3.65	108	4.35	565	3.90	135	3.95	157	4.95	803	3.55	100	2.55	28	3.10	94	2.60	54	25
26	3.50	96	4.15	236	3.95	157	4.00	180	4.40	657	3.80	124	2.55	28	2.30	38	3.15	99	26
27	3.65	108	3.65	108	4.05	209	4.00	180	4.25	361	2.65	30	2.55	28	3.10	94	3.10	94	27
28	4.05	209	3.70	113	4.05	209	3.90	185	4.15	236	3.55	100	3.10	87	2.90	75	3.10	94	28
29	3.75	118	3.35	84	4.10	214	5.30	988	3.90	135	3.12	87	8.50	6,760	2.30	38	3.10	94	29
30	3.75	118	3.30	80	5.90	1,400	16.75	21,800	3.65	108	2.75	32	5.10	890	3.05	89	3.10	94	30
31	.....	.....	3.70	113	.....	.....	6.25	1,810	3.90	135	.....	.....	3.75	118	.....	.....	3.10	94	31
Totals	.....	49,725	.....	13,313	.....	25,547	.....	38,365	.....	10,964	.....	3,911	.....	9,347	.....	2,293	.....	2,853	.....
Mean	1,657.5		429.4		851.6		1,237.6		353.7		130.4		301.5		76.4		92.1		.....
Run-off, in inches	.334—		.089		.172		.255		.073		.026		.062		.015		.019		.....
Run-off, per square mile	.300—		.077		.154—		.226		.065		.023		.055—		.013		.017		.....

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BEVERLY STATION. ON SALINE RIVER.

This station was established April 18, 1895, by Mr. Arthur P. Davis, at the iron highway bridge one-half mile southwest of town. The first observer was Chas. Reid, who removed, and Jerome Wilson was appointed and is still acting. The first gage was destroyed by high water, and a second was put in on wooden trestles; it is an inclined timber, graduated in feet and tenths up to 17 feet, and graduations are continued on the iron bridge pier on the south side. The bench mark is the top of the lower iron strut connecting the piers and at down-stream end. Its elevation is 18.95 feet above the zero of the new rod. The channel is muddy and shifting, and the high water of July 4, 1895, lowered the bottom of the river. The following tables give the discharge measurements made here and the daily gage height and discharges:

LIST of discharge measurements made on Saline river, at Beverly, Kas.

No.	Date.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (square feet).	Mean velocity (feet per second).	Discharge (second feet).	Remarks.
	1895.							
1..	Apr. 18	A. P. Davis.....	28	1.50	16	1.31	22	Haskell meter.
2..	June 8	W. G. Russell...	3	9.90	448	2.77	1,238	Price "
3..	July 22	" " ...	3	6.10	129	1.76	226	" "
4..	Aug. 22	" " ...	3	4.70	50—	1.52	76	" "
5..	Sept. 21	" " ...	3	3.85	30	.42	13	" "
6..	Nov. 12	" " ...	3	4.30	52	1.09—	56	" "
7..	Dec. 14	" " ...	28	4.60	59	1.19	70	Haskell "
8..	" 23	" " ...	3	4.10	44	.57	25	Price "
	1896.							
9..	Jan. 16	W. G. Russell...	28	4.10	47	.69	33	Haskell meter.
10..	" 28	" " ...	28	4.05	40	.77	31	" "
11..	Feb. 14	" " ...	28	4.25	48	.96	46	" "
12..	Apr. 14	" " ...	28	9.70	249	2.79	693	" "
13..	May 15	" " ...	28	5.75	112	1.83	204	" "
14..	June 6	" " ...	28	9.20	250	2.69	674	" "
15..	July 11	" " ...	28	7.50	174	2.82	493	" "
16..	Aug. 13	" " ...	28	4.80	78	1.23	96	" "
17..	Sept. 1	" " ...	55	4.60	73	1.00	76	Price "
18..	" 25	" " ...	55	4.40	73	.78	56	" "
19..	Oct. 21	" " ...	55	4.30	70	.69	48	" "
20..	Nov. 5	" " ...	55	4.90	88	1.22	107	" "

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Daily mean gage height and discharge in second feet of the Saline river. Drainage area, 2,730 square miles.
Observer, CHAS. REID.

Day.	July, 1895.		August, 1895.		September, 1895.		October, 1895.		November, 1895.		December, 1895.		January, 1896.		February, 1896.		March, 1896.		Day.
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	
1	2.85	124	4.60	70	4.70	76	4.05	28	4.25	48	3.85	13	4.20	41	4.45	60	4.35	52	1
2	2.80	117	4.75	79	4.95	92	3.85	13	4.10	30	4.00	22	4.20	41	4.50	65	4.20	41	2
3	2.80	117	5.55	145	4.80	82	3.85	13	4.20	41	3.95	18	4.00	30	4.45	60	4.15	37	3
4	2.85	124	7.00	339	4.95	92	3.95	18	4.20	41	3.95	18	3.85	26	4.80	96	4.10	33	4
5	11.35	2,300	5.95	199	4.80	82	4.00	22	4.20	41	4.10	30	3.85	26	4.70	85	4.25	46	5
6	17.15	10,000	5.50	140	4.55	67	4.20	41	3.90	15	4.15	35	4.40	56	4.45	60	4.25	46	6
7	9.45	1,012	5.05	99	4.55	67	4.05	28	4.05	28	4.15	35	4.30	49	4.35	52	4.30	49	7
8	8.80	753	4.80	82	4.45	62	4.10	30	4.45	62	4.05	28	4.40	56	4.35	52	4.30	49	8
9	5.90	191	4.65	73	4.15	35	4.25	42	4.35	56	3.95	18	4.15	37	4.25	46	4.45	60	9
10	5.55	145	5.15	107	4.25	48	4.25	42	4.15	35	4.20	41	4.25	46	4.15	37	4.25	46	10
11	5.80	176	5.10	103	4.35	58	4.20	41	3.85	13	4.15	35	4.30	49	4.25	46	4.50	65	11
12	6.00	207	6.50	289	4.20	41	3.95	18	4.25	48	4.00	22	4.55	70	4.25	46	4.35	52	12
13	5.85	183	5.35	124	4.15	35	3.80	11	4.20	41	4.20	41	4.50	65	4.35	52	4.30	49	13
14	5.65	157	5.35	124	4.10	30	4.35	58	4.30	56	4.40	47	4.50	65	4.35	52	4.40	56	14
15	5.60	151	4.95	92	4.05	28	4.20	41	4.30	56	4.50	57	4.40	56	4.30	49	4.40	56	15
16	5.30	120	4.85	85	4.00	22	4.15	35	3.75	9	4.20	31	4.30	49	4.10	33	4.45	60	16
17	5.25	115	4.70	76	4.00	22	4.10	30	4.20	41	4.20	31	4.50	65	4.15	37	4.25	46	17
18	5.05	99	4.80	82	4.00	22	3.60	6	4.20	41	4.40	47	4.45	60	4.20	41	4.40	56	18
19	5.00	96	4.60	70	4.00	22	4.00	22	4.20	41	4.25	35	4.50	65	4.15	37	4.25	46	19
20	4.95	92	4.75	79	3.95	18	4.30	56	3.95	18	4.30	38	4.40	56	4.40	56	4.35	52	20
21	4.95	92	4.60	70	3.95	18	3.95	18	3.95	18	4.30	38	4.55	70	4.25	46	4.30	49	21
22	6.10	226	4.50	65	3.90	15	4.00	22	3.90	15	3.95	18	4.55	70	4.25	46	4.20	41	22
23	6.90	324	4.40	60	4.20	41	3.90	15	4.10	30	4.10	25	4.60	76	4.35	52	4.25	46	23
24	6.30	246	4.65	73	3.80	11	4.15	35	3.80	11	4.25	35	4.55	70	4.20	41	4.20	41	24
25	5.40	129	4.40	60	3.95	18	4.05	26	3.85	13	4.30	38	4.40	56	4.15	37	4.30	49	25
26	5.15	107	4.40	60	3.80	11	4.10	30	3.95	18	4.45	51	4.25	46	4.20	41	4.40	56	26
27	4.95	92	4.35	58	3.80	11	3.90	15	4.20	41	4.35	42	4.25	46	4.30	49	4.30	49	27
28	4.70	76	4.40	60	3.75	9	3.90	15	3.90	15	4.50	57	4.20	41	4.40	56	4.25	46	28
29	4.80	82	4.40	60	3.75	9	3.80	11	4.15	35	4.35	42	4.15	37	4.25	46	4.40	56	29
30	4.70	76	4.45	62	3.80	11	3.95	18	3.95	18	4.20	31	4.20	46	.....	.....	4.25	46	30
31	4.65	73	4.45	62	.....	.....	4.15	35	.....	.....	3.85	13	4.40	56	.....	.....	4.10	33	31
Totals	.....	17,802	.....	3,127	.....	1,153	.....	843	.....	975	.....	1,030	.....	1,622	.....	1,476	.....	1,509	.....
Mean	574.3		100.9		38.4		27.2		82.5		33+		52.3		50.9		48.7		.....
Run-off, in inches	.20		.035		.012+		.009		.010+		.011		.022		.020		.020		.....
Run-off, per sq. mile	.18—		.031		.011—		.008		009		.010		.019+		.018+		.018—		.....

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Daily mean gage height and discharge in second feet of the Saline river. Drainage area, 2,730 square miles. Observer, CHAS. REID.

DAY.	April, 1896.		May, 1896.		June, 1896.		July, 1896.		August, 1896.		September, 1896.		October, 1896.		November, 1896.		December, 1896.		DAY.
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	
1	4.15	37	5.20	132	20.25	10,000	7.00	380	5.30	143	4.40	56	4.20	41	5.65	188	4.20	41	1
2	4.30	49	5.35	148	23.00	15,000	6.40	284	4.80	96	4.50	65	4.35	52	5.25	137	4.20	48	2
3	4.35	52	5.10	122	23.50	16,000	6.95	371	4.70	85	4.45	60	4.40	56	4.90	107	4.40	56	3
4	4.20	41	10.55	1,200	21.50	12,000	7.15	410	4.80	96	4.20	41	4.20	41	4.90	107	4.35	52	4
5	4.15	37	8.85	632	13.05	3,100	6.95	371	4.60	76	4.30	49	4.20	41	4.75	93	4.30	48	5
6	4.20	41	5.30	143	9.20	674	6.15	252	5.00	113	4.15	37	4.40	56	4.75	93	4.30	48	6
7	4.15	37	4.85	99	12.10	2,000	5.75	203	5.00	113	4.35	52	4.45	60	4.75	93	4.15	37	7
8	4.60	76	4.70	85	10.55	1,200	7.35	455	5.05	117	4.30	49	4.35	52	4.65	82	4.80	98	8
9	4.90	103	4.75	90	8.50	592	6.00	234	4.65	80	4.10	33	4.35	52	4.45	61	4.65	82	9
10	4.65	80	4.65	80	6.90	382	5.75	203	4.60	76	4.25	46	4.35	52	4.70	87	4.55	71	10
11	4.50	65	4.65	80	6.50	298	8.10	549	4.85	99	4.50	65	4.15	37	4.65	82	4.65	82	11
12	4.45	60	4.70	85	6.20	258	9.35	679	4.55	70	4.30	49	4.35	52	4.45	61	4.50	65	12
13	6.40	56	7.30	443	6.05	240	6.70	330	4.65	80	4.40	56	4.30	49	4.30	48	4.40	56	13
14	9.70	693	7.40	467	5.90	223	5.85	217	4.45	60	4.40	56	4.35	52	4.55	71	4.05	31	14
15	5.80	212	5.60	181	5.70	196	5.55	174	4.20	41	4.40	56	4.35	52	4.30	48	4.70	86	15
16	5.05	117	7.25	431	5.60	181	5.45	160	4.75	90	4.50	65	4.35	52	4.50	65	4.50	65	16
17	5.50	167	6.50	298	5.80	212	5.30	143	4.95	108	4.55	70	4.30	49	4.60	77	4.55	71	17
18	5.40	154	5.80	211	5.75	208	8.50	592	4.85	90	4.45	60	4.20	41	4.50	65	4.25	45	18
19	5.05	117	5.75	203	5.50	167	7.45	480	4.70	85	4.60	76	4.25	46	4.60	77	4.50	65	19
20	4.80	96	7.20	420	5.50	167	7.25	431	4.80	96	4.70	85	4.10	33	4.40	56	4.25	45	20
21	4.90	103	6.55	306	10.80	1,400	5.95	228	4.75	90	4.75	90	4.25	46	4.40	56	4.35	52	21
22	4.75	90	5.75	203	7.55	497	5.45	160	4.75	90	4.60	76	4.35	52	4.55	71	4.30	48	22
23	4.70	85	5.20	132	8.85	632	5.25	137	7.50	493	4.50	65	4.35	52	4.20	41	4.55	71	23
24	4.65	80	4.95	108	6.80	346	5.85	217	5.95	228	4.50	65	4.25	46	4.30	48	4.60	76	24
25	4.70	85	4.70	85	6.20	258	5.55	174	5.10	122	4.40	56	4.05	31	4.55	71	4.50	65	25
26	6.60	314	4.60	76	6.75	338	5.10	122	4.85	99	4.35	52	4.30	49	4.55	71	4.15	37	26
27	9.30	677	4.55	70	8.30	570	5.00	113	4.65	80	4.35	52	4.15	37	4.30	48	4.30	48	27
28	7.35	455	4.45	60	8.10	549	4.95	108	4.70	85	4.40	56	4.40	56	4.35	52	4.30	48	28
29	5.75	203	4.40	56	8.00	539	4.90	103	4.55	70	4.30	49	5.75	203	4.30	48	4.30	48	29
30	5.30	143	4.25	45	7.90	529	6.90	382	4.50	65	4.45	60	15.35	6,180	4.25	45	4.30	48	30
31			13.00	3,000			5.85	217	4.45	60			7.10	400			4.30	48	31
Totals		4,535		9,692		68,730		8,859		3,305		1,739		8,068		2,249		1,781	
Mean	151.2		312.6		2,291—		285.8		106.6		57.9		260.3		75—		57.4		
Run-off, in inches	.062—		.132+		.936+		.120—		.045		.024		.109		.031		.0024		
Run-off, per sq. mile	.055		.114+		.839		.104+		.037		.021		.095		.027		.0022		

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ELLSWORTH STATION, ON SMOKY HILL RIVER.

This station was established April 17, 1895, by Mr. Arthur P. Davis, of the United States Geological Survey, for the purpose of obtaining the discharge of this river near the 98th meridian.

It is at the highway bridge on Douglas avenue, Ellsworth, Kas. The observer is Robert Martin, who lives about 100 yards north of the bridge. The gage consists of an inclined ash timber spiked to a post driven into the bed of the river, and marked from 1 foot up to 4.5 feet and the scale is continued on the bridge pier. Discharge measurements are made from the bridge. The bench mark consists of a nail driven in the base of a large box-elder tree near the southeast corner of the bridge, 90 feet from the gage. It is 13.07 feet above the zero of the rod. The channel is nearly straight both above and below the bridge, but the banks are low and liable to overflow. The bed of the stream is sandy and shifting, tending to deepen towards the left bank; in fact in July, 1896, the channel had left the main gage and a second gage 4 feet long was put in at the middle bridge pier, 90 feet north of the other. A second gage was established October 23, 1895. It was fastened to the down-stream pile of the fourth bent from the south end of the 'Frisco railroad bridge, west from the old gage 2,536 feet, being referred to the same elevation as the old gage. The difference of water height October 23, 1895, was 1.44 feet, the slope being 0.000568.

The following tables give discharge measurements and daily gage heights and discharges:

List of discharge measurements made on Smoky Hill river, at Ellsworth, Kas.

No.	Date.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (square feet).	Mean velocity (feet per second).	Discharge (second feet).	Remarks.
	1895.							
1..	Apr. 16	A. P. Davis.....	28	1.50	14	.84	12	Haskell meter.
2..	June 5	W. G. Russell...	3	9.05	1,854	2.91	5,402	Price "
3..	July 3	" ...	3	2.60	115	1.89—	217	" "
4..	Aug. 21	" ...	3	2.10	77	1.34	104	" "
5..	Sept. 20	" ...	3	1.50	29	.94	26	" "
6..	Oct. 23	" ...	3	1.35	21	.84	17	" "
7..	Dec. 6	" ...	3	1.35	19	.94	18	" "
8..	" 28	" ...	3	1.30	19	.95	18	" "
	1896.							
9..	Jan. 22	" ...	3	1.42	26	1.00	26	" "
10..	Mar. 19	" ...	3	1.24	18	.88	16	" "
11..	Apr. 13	" ...	3	3.04	221	1.75—	387	" "
12..	June 9	" ...	3	3.55	277	2.20	609	" "
13..	" 25	" ...	3	2.50	138	1.68—	232	" "
14..	" 29	" ...	3	3.40	296	1.73	511	" "
15..	July 18	" ...	3	3.05	242	1.78	431	" "
16..	" 25	" ...	3	2.00	81	1.58	128	" "
17..	Aug. 19	" ...	55	1.56	53	1.49	79	Price, large.
18..	Aug. 25	" ...	55	1.60	49	1.76	87	" "
19..	Sept. 22	" ...	55	1.68	63	1.63	102	" "
20..	Oct. 26	" ...	55	1.30	30	1.22	37	" "
21..	Nov. 2	" ...	55	1.80	82	1.85	153	" "
22..	" 20	" ...	55	1.20	33	1.04	34	" "
23..	Dec. 21	" ...	55	1.20	32	1.14	37	" "

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Daily mean gage height and discharge in second feet of the Smoky Hill river. Drainage area, 7,980 square miles.
Observer, ROBT. MARTIN.

DAY.	July, 1895.		August, 1895.		September, 1895.		October, 1895.		November, 1895.		December, 1895.		January, 1896.		February, 1896.		March, 1896.		DAY.
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	
1	2.55	202	3.25	344	2.27	135	1.40	19	1.40	19	1.35	17	1.50	49	1.40	24	1.30	18	1
2	2.75	244	3.25	344	2.15	112	1.40	19	1.40	19	1.35	17	1.50	49	1.50	49	1.28	17	2
3	2.55	202	3.07	307	2.05	93	1.40	19	1.40	19	1.30	14	1.43	28	1.50	49	1.35	20	3
4	3.30	357	2.95	283	1.98	79	1.45	22	1.35	17	1.32	15	1.43	28	1.50	49	1.28	17	4
5	16.55	21,000	2.95	283	1.92	68	1.45	22	1.40	19	1.40	19	1.35	20	1.50	49	1.30	18	5
6	9.75	7,500	2.95	283	1.86	62	1.45	22	1.40	19	1.45	22	1.32	19	1.50	49	1.30	18	6
7	7.25	2,349	2.95	283	1.80	52	1.45	22	1.40	19	1.38	18	1.28	17	1.40	24	1.30	18	7
8	6.00	1,343	2.82	258	1.80	52	1.45	22	1.40	19	1.25	11	1.43	28	1.30	18	1.30	18	8
9	5.05	878	2.83	260	1.77	48	1.42	20	1.40	19	1.25	11	1.43	28	1.35	20	1.30	18	9
10	4.50	676	2.77	248	1.73	44	1.40	19	1.40	19	1.35	17	1.35	20	1.48	41	1.30	18	10
11	4.29	587	3.00	293	1.70	41	1.40	19	1.35	17	1.35	17	1.35	20	1.40	24	1.28	17	11
12	3.95	515	2.75	244	1.70	41	1.40	19	1.35	17	1.35	17	1.32	19	1.40	24	1.28	17	12
13	3.65	438	2.55	202	1.67	39	1.40	19	1.40	19	1.32	15	1.43	28	1.40	24	1.22	15	13
14	3.52	407	2.43	170	1.65	37	1.40	19	1.40	19	1.37	18	1.35	20	1.40	24	1.37	21	14
15	3.35	368	2.40	162	1.63	35	1.40	19	1.40	19	1.35	17	1.32	19	1.40	24	1.37	21	15
16	3.15	324	2.47	180	1.60	33	1.40	19	1.40	19	1.35	17	1.32	19	1.40	24	1.28	17	16
17	3.05	303	2.28	136	1.57	31	1.40	19	1.40	19	1.40	19	1.28	17	1.35	20	1.37	21	17
18	3.00	293	2.20	121	1.55	29	1.38	18	1.40	19	1.40	19	1.28	17	1.35	20	1.32	19	18
19	3.05	303	2.12	107	1.53	28	1.35	17	1.40	19	1.40	19	1.30	18	1.35	20	1.25	16	19
20	3.65	438	2.10	104	1.50	26	1.35	17	1.35	17	1.40	19	1.35	20	1.32	19	1.30	18	20
21	4.75	762	2.10	104	1.50	26	1.35	17	1.35	17	1.38	18	1.32	19	1.32	19	1.30	18	21
22	3.15	324	2.08	98	1.50	26	1.35	17	1.35	17	1.37	18	1.35	20	1.35	20	1.30	18	22
23	3.05	303	2.07	96	1.50	26	1.35	17	1.40	19	1.40	19	1.32	19	1.35	20	1.30	18	23
24	3.80	476	2.08	98	1.50	26	1.35	17	1.30	14	1.37	18	1.40	24	1.30	18	1.30	18	24
25	4.80	782	2.07	96	1.47	24	1.32	15	1.30	14	1.35	17	1.45	33	1.30	18	1.28	17	25
26	4.30	610	2.00	82	1.45	22	1.30	14	1.27	12	1.35	17	1.37	21	1.30	18	1.30	18	26
27	4.33	619	1.93	70	1.45	22	1.30	14	1.30	14	1.35	17	1.52	57	1.30	18	1.30	18	27
28	4.40	642	1.92	68	1.43	21	1.30	14	1.30	14	1.35	17	1.43	28	1.30	18	1.28	17	28
29	4.00	529	1.90	65	1.40	19	1.30	14	1.33	16	1.30	14	1.40	24	1.30	18	1.20	14	29
30	3.70	451	1.92	68	1.40	19	1.38	18	1.35	17	1.33	16	1.40	24	.....	.....	1.20	14	30
31	3.30	357	3.00	293	.....	.....	1.40	19	.....	.....	1.30	14	1.40	24	.....	.....	1.20	14	31
Totals	.....	44,582	.....	5,750	.....	1,316	.....	567	.....	526	.....	523	.....	776	.....	762	.....	546	.....
Mean	1,438.1		185.5		43.9		18.3		17.5		16.9		25		26.2		17.6		.....
Run-off, in inches	.22		.03		.007		.003		.003		.0026		.004—		.004—		.002+		.....
Run-off, per sq. mile	.19		.025		.006		.002		.002		.0022		.003+		.003		.002		.....

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Daily mean gage height and discharge in second feet of the Smoky Hill river. Drainage area, 7,980 square miles.
Observer, ROBT. MARTIN.

DAY.	April, 1896.		May, 1896.		June, 1896.		July, 1896.		August, 1896.		September, 1896.		October, 1896.		November, 1896.		December, 1896.		Day.
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	
1	1.20	14	1.72	107	1.85	116	2.62	260	2.05	136	1.68	96	1.45	58	1.95	122	1.82	39	1
2	1.20	14	1.68	102	1.75	109	2.45	218	1.90	117	1.60	87	1.42	50	1.85	111	1.30	37	2
3	1.20	14	1.65	95	1.62	90	2.25	172	1.78	106	1.58	87	1.40	50	1.87	112	1.30	37	3
4	1.20	14	1.70	106	1.55	72	2.20	163	1.68	96	1.52	66	1.40	50	1.77	102	1.30	37	4
5	1.20	14	1.62	90	1.90	120	2.18	161	1.65	91	1.48	66	1.42	50	1.70	98	1.27	32	5
6	1.20	14	1.60	87	1.95	124	2.02	131	1.78	106	1.45	58	1.35	43	1.62	92	1.27	32	6
7	1.20	14	1.58	83	4.05	857	3.75	699	1.88	117	1.42	50	1.30	37	1.52	70	1.30	37	7
8	2.10	144	1.50	49	6.55	1,713	2.10	144	1.75	101	1.40	50	1.30	37	1.50	66	1.25	31	8
9	1.43	28	1.48	41	3.75	699	2.00	128	1.65	91	1.40	50	1.30	37	1.50	66	1.22	27	9
10	1.28	17	1.50	49	2.75	294	1.98	126	1.58	87	1.50	66	1.40	50	1.45	58	1.25	31	10
11	1.20	14	1.45	33	2.45	218	4.20	951	1.50	66	1.47	66	1.35	43	1.42	53	1.25	31	11
12	1.55	72	1.48	41	2.25	172	2.90	339	1.55	76	1.40	50	1.32	37	1.40	50	1.25	31	12
13	2.30	183	1.85	116	2.05	135	2.50	252	1.38	87	1.45	58	1.30	37	1.40	50	1.25	31	13
14	2.25	172	1.72	107	1.95	124	2.22	167	1.62	87	1.42	50	1.27	37	1.35	43	1.20	25	14
15	1.85	116	1.68	102	1.85	116	2.02	131	1.68	95	1.40	50	1.25	30	1.35	43	1.20	25	15
16	1.98	126	1.62	90	1.82	114	2.00	128	1.60	87	1.40	50	1.22	25	1.35	43	1.20	25	16
17	2.37	198	1.55	72	1.80	113	1.98	125	1.58	87	1.40	50	1.20	25	1.30	37	1.22	27	17
18	3.00	372	1.50	49	1.82	114	2.90	339	1.50	66	1.45	58	1.20	25	1.30	37	1.12	18	18
19	2.10	144	1.50	49	1.85	116	3.60	631	1.55	76	1.90	117	1.20	25	1.20	25	1.35	43	19
20	1.98	126	1.50	49	1.72	107	2.65	267	1.50	66	1.67	96	1.20	25	1.20	25	1.25	37	20
21	1.98	126	1.50	49	4.30	1,017	2.35	194	1.50	66	1.60	87	1.20	25	1.27	32	1.20	37	21
22	1.90	120	1.48	41	2.30	183	2.07	139	3.00	372	1.62	87	1.20	25	1.15	20	1.20	37	22
23	1.92	121	1.60	87	2.10	144	2.15	153	2.40	206	1.67	96	1.27	30	1.22	27	1.20	37	23
24	1.87	118	1.48	41	2.65	267	2.15	153	1.85	101	1.70	96	1.27	30	1.25	31	1.20	37	24
25	3.95	800	1.40	24	2.50	232	2.00	128	1.95	122	1.70	96	1.25	30	1.25	31	1.20	37	25
26	2.80	308	1.40	24	2.35	194	1.92	121	2.42	206	1.67	96	1.27	30	1.32	39	1.25	40	26
27	2.10	144	1.35	20	2.45	218	1.88	119	2.28	183	1.57	87	1.30	37	1.35	43	1.20	37	27
28	2.00	128	1.30	18	3.85	747	2.00	128	2.05	136	1.52	66	1.30	37	1.30	37	1.20	37	28
29	1.85	116	1.30	18	3.30	513	1.92	121	1.92	117	1.50	66	2.62	255	1.25	31	1.20	37	29
30	1.80	113	1.30	18	2.90	339	2.40	206	1.82	106	1.47	66	2.40	206	1.30	37	1.20	37	30
31	.....	.....	1.52	57	.....	.....	2.20	163	1.72	96	.....	.....	2.27	183	.....	.....	1.20	37	31
Totals	.....	3,904	.....	1,914	.....	9,377	.....	7,138	.....	3,553	.....	2,164	.....	1,659	.....	1,631	.....	1,046	....
Mean	130.1		61.7		312.6—		230.3		114.6		72.1		53.5		54.4		37.7		....
Run-off, in inches	.018		.009		.044—		.033		.016		.010		.008		.0075		.005		....
Run-off, per square mile	.016—		.008—		.039—		.029		.014		.009		.007		.0067		.0044		....

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HUTCHINSON STATION, ARKANSAS RIVER.

This station was established May 13, 1895, by Mr. Arthur P. Davis, of the United States Geological Survey. It is at south end of Main street, at the wagon bridge, Hutchinson, Kas. The observer is Daniel Lauer, who lives in the immediate vicinity. The gage consists of an oak timber painted white spiked to the oak pile of a triangular pier. It can be read from the bridge. The first bench mark is the upper cross-piece of the triangular pier. Its elevation is 8.35 feet above zero. A second bench mark is the top of the iron door-sill in the first brick building. Its elevation is 8.12 feet above zero.

Measurements of discharge are made from the bridge, or at very low water may be made by wading.

The following tables give discharge measurements and daily gage heights and discharges:

LIST of discharge measurements made on Arkansas river, at Hutchinson, Kas.

No.	Date.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (square feet).	Mean velocity (feet per second).	Discharge (second feet).	Remarks.
	1895.							
1..	May 13	A. P. Davis.....	3	1.30	.....	.90	10	Price meter.
2..	June 20	W. G. Russell...	3	3.40	749	1.98	1,471	" "
3..	July 27	" ...	3	5.65	3,127	3.93+	12,300	" "
4..	Aug. 31	" ...	3	2.73	557	1.86	1,037	" "
5..	Oct. 1	" ...	3	1.60	71	.80+	57	" "
6..	Nov. 13	" ...	3	1.50	64	.72+	46	" "
7..	Dec. 20	" ...	3	2.15	94	1.33	125	" "
8..	" 31	" ...	3	1.75	76	.64	49	" "
	1896.							
9..	Jan. 17	" ...	3	2.35	299	1.65+	494	" "
10..	" 29	" ...	3	2.80	430	1.79	791	" "
11..	Feb. 13	" ...	3	2.15	178	1.74—	308	" "
12..	Apr. 15	" ...	3	1.67	70+	1.10	78	" "
13..	June 30	" ...	3	1.60	82	1.13	93	" "
14..	July 14	" ...	3	1.40	29	.98	28	" "
15..	" 31	" ...	3	1.80	98	1.39	137	" "
16..	Aug. 21	" ...	55	1.40	43	1.21	52	Price, large.
17..	Sept. 24	" ...	55	1.30	30	.85	25	" "
18..	Oct. 22	" ...	55	1.55	59	1.56	93	" "
19..	Nov. 4	" ...	55	1.60	62	1.60	99	" "
20..	Dec. 9	" ...	3	1.60	52	1.00	52	" small.

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Daily mean gage height and discharge in second feet of the Arkansas river, Hutchinson, Kas. Drainage area, 34,000 square miles. Observer, DANIEL LAUER.

Day.	July, 1895.		August, 1895.		September, 1895.		October, 1895.		November, 1895.		December, 1895.		January, 1896.		February, 1896.		March, 1896.		Day.
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	
1	2.50	574	4.60	4,610	3.00	1,203	1.60	57	1.60	57	1.50	46	1.95	200	2.50	578	1.90	178	1
2	2.40	444	4.45	4,000	3.00	1,203	1.60	57	1.55	51	1.50	46	1.90	178	2.50	578	1.85	160	2
3	2.65	850	4.40	3,815	2.85	1,117	1.60	57	1.60	57	1.50	46	1.85	160	2.45	548	1.70	115	3
4	2.50	574	4.65	4,830	2.65	850	1.70	73	1.60	57	1.50	46	1.80	143	2.40	520	1.70	115	4
5	3.20	1,330	4.75	5,295	2.55	658	1.75	84	1.60	57	1.50	46	2.15	308	2.40	520	1.85	160	5
6	3.10	1,265	4.40	3,815	2.50	574	1.70	73	1.60	57	1.60	54	2.20	346	2.40	520	1.90	178	6
7	3.35	1,434	4.75	5,295	2.40	444	1.70	73	1.60	57	1.60	54	1.95	200	2.40	520	1.80	143	7
8	3.90	2,370	5.20	8,040	2.40	444	1.70	73	1.55	51	1.60	54	1.90	178	2.40	520	1.80	143	8
9	3.80	2,155	4.70	5,050	2.50	574	1.70	73	1.50	46	1.60	54	1.85	160	2.30	440	1.90	178	9
10	3.75	2,057	4.40	3,815	2.50	574	1.70	73	1.50	46	1.60	54	1.85	160	2.20	346	1.95	200	10
11	3.40	1,471	4.30	3,475	2.50	574	1.60	57	1.50	46	1.50	46	1.80	143	2.20	346	1.90	178	11
12	3.20	1,330	4.10	2,870	2.50	574	1.60	57	1.50	46	1.50	46	1.90	178	2.15	308	1.90	178	12
13	3.10	1,265	4.00	2,610	2.35	394	1.60	57	1.50	46	1.40	37	2.10	276	2.10	276	1.85	160	13
14	2.95	1,173	4.00	2,610	2.20	286	1.60	57	1.50	46	1.40	37	2.25	391	2.10	276	1.90	178	14
15	2.80	1,090	3.80	2,155	2.20	286	1.60	57	1.50	46	1.40	37	2.40	520	2.10	276	1.90	178	15
16	2.65	850	3.80	2,155	2.15	245	1.60	57	1.50	46	1.60	54	2.40	520	2.00	222	2.25	391	16
17	2.55	658	3.75	2,056	2.00	158	1.60	57	1.50	46	1.50	73	2.40	520	2.00	222	1.85	160	17
18	3.25	1,363	3.70	1,958	1.95	140	1.55	51	1.40	37	2.05	108	2.30	440	2.00	222	1.90	178	18
19	3.90	2,370	3.55	1,700	1.90	123	1.50	46	1.40	37	2.30	159	2.35	494	2.05	247	1.95	200	19
20	3.75	2,057	3.40	1,470	1.80	95	1.50	46	1.40	37	2.25	147	2.40	520	2.10	276	1.90	178	20
21	3.55	1,700	3.35	1,434	1.80	95	1.50	46	1.30	29	2.15	125	2.40	520	2.10	276	1.80	143	21
22	3.45	1,545	3.15	1,297	1.80	95	1.50	46	1.30	29	2.10	116	2.40	520	2.15	308	1.80	143	22
23	3.40	1,471	3.00	1,203	1.80	95	1.50	46	1.30	29	2.00	100	2.50	578	2.10	276	1.80	143	23
24	3.50	1,618	2.85	1,117	1.80	95	1.50	46	1.30	29	2.00	100	2.45	548	2.10	276	1.75	128	24
25	3.65	1,870	2.80	1,090	1.70	73	1.50	46	1.30	29	2.00	100	2.40	520	2.10	276	1.70	115	25
26	5.20	6,810	2.70	958	1.70	73	1.50	46	1.30	29	2.40	107	2.85	833	2.10	276	1.70	115	26
27	5.65	12,300	2.75	1,024	1.70	73	1.45	41	1.30	29	2.35	99	2.90	878	2.05	247	1.60	93	27
28	5.95	16,400	2.85	1,117	1.70	73	1.40	37	1.30	29	2.05	63	2.80	791	1.95	200	1.60	93	28
29	6.15	19,600	2.80	1,090	1.60	57	1.40	37	1.50	46	1.80	50	2.75	750	1.90	178	1.60	93	29
30	6.15	19,600	2.75	1,024	1.60	57	1.50	46	1.50	46	1.80	50	2.60	641	.....	.....	1.55	69	30
31	5.40	9,710	2.80	1,090	.....	.....	1.60	57	.....	.....	1.75	48	2.50	578	.....	.....	1.50	51	31
Totals	.....	119,304	.....	84,089	.....	11,252	.....	1,745	.....	1,293	.....	2,202	.....	13,192	.....	10,074	.....	4,735	...
Mean	3,848.5		2712—		375+		56.3		43.1		71		425.6—		347.4		152.7		....
Run-off, in inches	.13+		.09		.012		.0019+		.0014		.0024		.014		.011		.005		....
Run-off, per square mile	.11+		.08—		.010		.0017—		.0013		.0021		.012+		.010		.004+		....

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Daily mean gage height and discharge in second feet of the Arkansas river. Drainage area, 34,000 square miles.
Observer, DANIEL LAUER.

Day.	April, 1896.		May, 1896.		June, 1896.		July, 1896.		August, 1896.		September, 1896.		October, 1896.		November, 1896.		December, 1896.		Day.
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	
1	1.50	51	1.60	93	1.30	25	1.55	69	1.80	143	1.20	16	1.30	25	1.75	129	Ice.	39	1
2	1.50	51	1.55	69	1.30	25	1.50	51	1.65	104	1.20	16	1.30	25	1.60	99	Ice.	39	2
3	1.50	51	1.50	51	1.30	25	1.55	69	1.80	143	1.20	16	1.30	25	1.60	99	1.70	80	3
4	1.50	51	1.50	51	1.30	25	1.60	93	1.90	178	1.20	16	1.30	25	1.60	99	1.60	52	4
5	1.50	51	1.45	38	1.30	25	1.50	51	1.85	160	1.20	16	1.30	25	1.60	99	1.60	52	5
6	1.50	51	1.40	28	1.30	25	1.50	51	1.80	143	1.20	16	1.30	25	1.60	99	1.60	52	6
7	1.45	38	1.40	28	2.35	494	1.50	51	1.80	143	1.20	16	1.30	25	1.60	99	1.60	52	7
8	1.50	51	1.40	28	2.65	676	1.50	51	1.80	143	1.20	16	1.30	25	1.50	63	1.60	52	8
9	1.50	51	1.40	28	2.00	222	1.50	51	1.65	104	1.20	16	1.30	25	1.50	63	1.60	52	9
10	1.45	38	1.50	51	1.80	143	1.55	69	1.60	99	1.20	16	1.40	39	1.50	63	1.60	52	10
11	1.45	38	1.45	38	1.70	115	1.50	51	1.50	63	1.20	16	1.40	39	1.50	63	1.60	52	11
12	1.55	69	1.40	28	1.70	115	1.45	38	1.50	63	1.20	16	1.30	25	1.50	63	1.60	52	12
13	1.70	115	1.40	28	1.65	103	1.40	28	1.50	63	1.20	16	1.30	25	1.50	63	1.60	52	13
14	1.65	103	1.50	51	1.55	69	1.40	28	1.40	39	1.50	63	1.30	25	1.50	63	1.60	52	14
15	1.60	93	1.60	93	1.50	51	1.40	28	1.40	39	1.45	51	1.30	25	1.50	63	1.60	52	15
16	1.65	103	1.70	115	1.50	51	1.50	51	1.40	39	1.35	32	1.30	25	1.50	63	1.60	52	16
17	1.90	178	1.70	115	1.60	93	1.60	93	1.40	39	1.30	25	1.30	25	1.50	63	1.60	52	17
18	2.20	346	1.65	103	1.55	69	2.30	440	1.40	39	1.40	39	1.30	25	1.50	63	1.80	110	18
19	2.15	308	1.55	69	1.50	51	3.15	1,138	1.40	39	1.55	81	1.30	25	1.50	63	1.70	80	19
20	2.10	276	1.55	69	1.40	28	2.65	676	1.40	39	1.40	39	1.30	25	1.50	63	1.60	52	20
21	2.00	222	1.50	51	1.60	93	2.25	391	1.40	39	1.35	32	1.30	25	1.50	63	1.60	52	21
22	2.00	222	1.50	51	1.80	143	2.20	347	1.40	39	1.30	25	1.50	63	1.50	63	1.60	52	22
23	2.05	247	1.50	51	2.35	494	2.20	347	1.30	25	1.30	25	1.50	63	1.50	63	1.60	52	23
24	1.95	200	1.50	51	2.65	676	2.85	833	1.30	25	1.30	25	1.50	63	1.40	39	1.60	52	24
25	1.90	178	1.40	28	2.30	440	3.15	1,138	1.30	25	1.30	25	1.50	63	1.40	39	1.60	52	25
26	1.80	143	1.50	51	1.95	200	2.40	520	1.30	25	1.30	25	1.50	63	2.00	222	1.60	52	26
27	1.80	143	1.60	93	1.75	128	2.15	368	1.30	25	1.30	25	1.50	63	2.00	222	1.60	52	27
28	1.85	160	1.45	38	1.70	115	2.00	222	1.30	25	1.30	25	1.50	63	Ice.	39	1.60	52	28
29	1.75	128	1.40	28	1.70	115	1.95	200	1.30	25	1.30	25	2.00	222	Ice.	39	1.60	52	29
30	1.65	103	1.30	25	1.60	93	1.85	160	1.30	25	1.30	25	2.05	249	Ice.	39	1.60	52	30
31	.....	.....	1.30	25	.....	.....	1.80	143	1.30	25	.....	.....	1.85	160	.....	.....	1.60	52	31
Totals	.....	3,859	.....	1,666	.....	4,927	.....	7,786	.....	2,125	.....	795	.....	1,625	.....	2,370	.....	1,600	...
Mean	128.6		53.7		164.2		251.2		68.5		26.5		52.4		79.0		51.6		...
Run-off, in inches	.004+		.002		.005		.0087		.0023		.0009		.0018		.0027−		.0018−		...
Run-off, per sq. mile	.003+		.002−		.005−		.0077		.0021		.0008		.0016		.0024		.0016−		...

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KIOWA STATION, MEDICINE RIVER.

This station was established May 6, 1895, by Mr. Arthur P. Davis, of the United States Geological survey, and is located at the wagon bridge 3½ miles east of the center of the town of Kiowa, Barber county, Kansas. The observer is J. M. Fisher, living about three-fourths of a mile from the bridge. The gage is a vertical oak plank fastened by spikes to a pile of the bridge bent. This is painted and graduated from 0.8 foot to 13.3 feet. The mark 11.1 of this scale is at the same elevation as the top of the plate or cross-timber resting on top of the piles to which the gage is fastened; that is, the first pier counting from the south. Measurements are made from the bridge at high water and by wading at low water. The bed of the stream is wide and consists entirely of sand, and is very changing. This station was discontinued October 31, 1896.

The following tables give discharge measurements and daily gage heights and discharges:

LIST of discharge measurements made on Medicine river, at Kiowa, Kas.

No.	Date.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (square feet).	Mean velocity (feet per second).	Discharge (second feet).	Remarks.
	1895.							
1..	May 6	A. P. Davis.....	3	2.35	.....	.91	22	Price meter.
2..	June 21	W. G. Russell...	3	2.40	49	1.34	66	" "
3..	July 25	" " ...	3	3.20	173	1.70	294	" "
4..	Sept. 1	" " ...	3	2.60	38	1.06	40	" "
5..	Oct. 29	" " ...	3	2.40	29	.68	15	" "
6..	Dec. 21	" " ...	3	2.65	45	1.22	54	" "
	1896.							
7..	May 22	W. G. Russell...	3	3.62	111	1.13	126	Price meter.
8..	Aug. 1	" " ...	3	2.50	30	1.11	34	" "
9..	" 3	" " ...	3	2.40	28	1.14	32	" "
10..	" 10	J. M. Fisher.....	3	1.90	5	.74	4	" "
11..	" 18	" "	3	1.80	2	.67	1	" "
12..	" 22	" "	3	1.70	1—	.52	.....	" "
13..	" 28	" "	3	1.40	0	.....	.....	" "
14..	Sept. 21	" "	3	2.50	31	1.15	36	" "
15..	" 28	" "	3	2.10	6+	.75	5	" "
16..	Oct. 5	" "	3	2.20	9+	.78	7	" "
17..	" 12	" "	3	2.40	23	1.00	23	" "
18..	" 19	" "	3	2.30	17	.92	15	" "
19..	" 23	" "	3	2.80	61—	1.12	68	" "
20..	" 29	" "	3	3.00	105	1.23	130	" "

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Daily mean gage height and discharge in second feet of the Medicine river. Drainage area, 1,300 square miles.
Observer, J. M. FISHER.

DAY.	July, 1895.		August, 1895.		September, 1895.		October, 1895.		November, 1895.		December, 1895.		January, 1896.		February, 1896.		DAY.
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	
1	3.95	1,190	2.10	12	2.55	32	1.00	5	2.45	20	2.30	14	2.50	36	2.50	36	1
2	3.50	515	2.10	12	2.90	110	1.00	5	2.65	48	2.30	14	2.60	44	2.50	36	2
3	3.10	248	2.00	11	2.85	94	1.30	6	2.55	25	2.20	13	2.60	44	2.50	36	3
4	2.90	167	2.00	11	2.75	67	1.50	7	2.50	25	2.20	13	2.70	55	2.60	44	4
5	2.80	138	2.00	11	2.65	48	1.60	8	2.50	25	2.10	12	2.70	55	2.60	44	5
6	2.75	126	1.85	9	2.45	20	2.20	13	2.60	40	2.10	12	2.60	44	2.60	44	6
7	2.55	87	1.80	9	2.40	15	2.50	25	2.70	56	2.10	12	2.60	44	2.70	55	7
8	2.75	126	1.75	8	2.30	14	2.50	25	3.00	154	2.10	12	2.60	44	2.70	55	8
9	2.65	100	1.70	8	2.25	13	2.40	15	2.95	132	2.20	13	2.60	44	2.70	55	9
10	2.50	79	2.45	20	2.10	12	2.40	15	2.70	56	2.20	13	2.70	55	2.70	55	10
11	2.45	72	3.40	427	2.10	12	2.35	14	2.65	48	2.40	15	2.80	68	2.60	44	11
12	2.40	66	2.80	78	2.00	11	2.30	14	2.60	40	2.40	15	2.70	55	2.60	44	12
13	2.40	66	2.70	56	2.00	11	2.20	13	2.50	25	2.40	15	2.60	44	2.60	44	13
14	2.50	79	2.40	15	1.95	10	2.20	13	2.55	32	2.50	25	2.60	44	2.60	44	14
15	2.40	66	2.40	15	1.90	10	2.25	13	2.80	78	2.50	25	2.60	44	2.60	44	15
16	2.30	55	2.35	14	1.90	10	2.30	14	3.00	154	2.50	25	2.70	55	2.50	36	16
17	2.30	55	2.30	14	1.90	10	2.40	15	2.90	110	2.50	25	2.80	68	2.50	36	17
18	2.35	60	2.10	12	1.90	10	2.40	15	2.85	94	2.60	42	2.75	61	2.60	44	18
19	2.55	87	1.85	9	1.80	9	2.20	13	2.75	67	2.85	156	2.65	49	2.70	55	19
20	5.55	87	1.75	8	1.80	9	2.20	13	2.65	48	2.65	54	2.60	44	2.70	55	20
21	2.70	115	1.70	8	1.60	8	2.20	13	2.55	32	2.60	42	2.55	40	2.70	55	21
22	3.55	563	1.70	8	1.50	7	2.20	13	2.50	25	2.60	42	2.50	36	2.60	44	22
23	3.50	515	1.75	8	1.50	7	2.30	14	2.50	25	2.60	42	2.50	36	2.50	36	23
24	3.10	248	2.30	14	1.40	7	2.45	20	2.50	25	2.45	20	2.50	36	2.50	36	24
25	2.95	187	2.65	48	1.40	7	2.55	32	2.45	20	2.50	25	2.60	44	2.40	23	25
26	2.80	78	2.40	15	1.30	6	2.50	25	2.40	15	2.40	15	2.60	44	2.40	23	26
27	2.60	40	2.25	13	1.25	6	2.40	15	2.40	15	2.40	15	2.60	44	2.40	23	27
28	2.40	15	2.10	12	1.20	6	2.40	15	2.30	14	2.40	15	2.60	44	2.50	36	28
29	2.35	15	1.90	10	1.10	5	2.40	15	2.30	14	2.40	15	2.60	44	2.50	36	29
30	2.25	13	1.95	10	1.00	5	2.30	14	2.30	14	2.50	25	2.50	36	.....	.....	30
31	2.15	12	2.10	12	.....	.....	2.30	14	.....	.....	2.50	25	2.50	36	.....	.....	31
Totals	.....	5,270	.....	917	.....	591	.....	451	.....	1,476	.....	806	.....	1,437	.....	1,218	.....
Mean		170		30—		20—		15—		49+		26		46.4		42	.....
Run-off, in inches		.15		.028		.017		.013		.042		.023		.038		.035—	.....
Run-off, per sq. mile		.13		.028		.015		.011		.037		.020		.035+		.032	.....

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Daily mean gage height and discharge in second feet of the Medicine river. Drainage area, 1,300 square miles.
Observer, J. M. FISHER.

Day.	March, 1896.		April, 1896.		May, 1896.		June, 1896.		July, 1896.		August, 1896.		September, 1896.		October, 1896.		Day.
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	
1	2.40	23	2.40	23	2.65	49	2.30	15	3.65	450	2.40	23	1.40	.....	2.10	5	1
2	2.40	23	2.40	23	2.50	36	2.30	15	3.50	345	2.40	23	1.40	.....	2.20	7	2
3	2.40	23	2.40	23	2.50	36	2.20	7	3.10	156	2.40	23	1.40	.....	2.20	7	3
4	2.40	23	2.40	23	2.50	36	2.20	7	2.80	68	2.40	23	1.40	.....	2.20	7	4
5	2.30	15	2.20	7	2.50	36	2.10	5	2.80	68	2.40	23	1.40	.....	2.20	7	5
6	2.30	15	2.20	7	2.40	23	1.90	4	2.70	55	2.40	23	1.40	.....	2.10	5	6
7	2.30	15	2.00	4	2.40	23	1.65	.....	2.60	44	2.30	15	1.40	.....	2.20	7	7
8	2.40	23	2.00	4	2.40	23	1.30	.....	2.60	44	2.30	15	1.40	.....	2.20	7	8
9	2.40	23	2.00	4	2.30	15	1.40	.....	2.60	44	2.00	4	.....	.....	2.20	7	9
10	2.40	23	1.90	4	2.20	7	1.20	.....	2.90	98	2.00	4	.....	.....	2.30	15	10
11	2.45	29	1.90	4	2.20	7	1.20	.....	2.95	114	2.00	4	.....	.....	2.35	19	11
12	2.50	36	2.20	7	2.20	7	1.20	.....	2.90	98	1.90	4	.....	.....	2.40	23	12
13	2.60	44	2.50	36	2.30	15	1.20	.....	2.85	83	1.90	4	2.00	4	2.40	23	13
14	2.60	44	2.55	40	2.30	15	.....	.....	3.25	213	1.80	1	2.00	4	2.40	23	14
15	2.70	55	2.60	44	2.30	15	.....	.....	3.85	585	1.80	1	2.00	4	2.40	23	15
16	2.65	49	2.60	44	2.20	7	.....	.....	5.90	24,600	1.80	1	2.00	4	2.40	23	16
17	2.60	44	2.60	44	2.10	5	.....	.....	5.00	4,800	1.80	1	2.00	4	2.30	15	17
18	2.50	36	2.75	61	2.10	5	.....	.....	5.20	6,900	1.80	1	2.00	4	2.30	15	18
19	2.50	36	2.75	61	2.15	6	.....	.....	5.60	14,200	1.80	1	2.10	5	2.30	15	19
20	2.50	36	2.70	55	2.20	7	.....	.....	3.90	700	1.70	1	2.35	19	2.40	23	20
21	2.50	36	3.15	171	2.35	19	2.00	4	3.70	490	1.70	1	2.35	19	2.40	23	21
22	2.50	36	2.75	61	2.40	23	2.20	7	3.60	410	1.70	1	2.20	7	2.55	40	22
23	2.60	44	2.70	55	3.20	187	4.00	780	3.40	288	1.70	1	2.20	7	2.80	68	23
24	2.60	44	2.65	49	3.00	130	2.95	114	3.00	130	1.60	.....	2.20	7	2.90	98	24
25	2.60	44	2.50	36	2.80	68	2.40	23	2.75	61	1.60	.....	2.20	7	2.85	83	25
26	2.60	44	2.50	36	2.70	55	5.50	11,860	2.75	61	1.50	.....	2.20	7	2.80	68	26
27	2.60	44	2.60	44	2.60	44	5.35	9,070	2.60	44	1.50	.....	2.10	5	2.60	44	27
28	2.65	49	2.80	68	2.55	40	4.75	3,050	2.55	40	1.40	.....	2.10	5	2.60	44	28
29	2.45	29	2.85	83	2.45	29	4.25	1,240	2.50	36	1.40	.....	2.10	5	3.00	130	29
30	2.40	23	2.80	68	2.40	23	3.95	745	2.55	40	1.40	.....	2.10	5	2.95	114	30
31	2.40	23	.....	.....	2.30	15	.....	.....	2.50	36	1.40	.....	.....	.....	2.75	61	31
Totals	.....	1,031	.....	1,189	.....	1,008	.....	26,956	.....	55,301	.....	198	.....	122	.....	1,049	.....
Mean		33.3		39.6		32.4		898.5		1,784—		6.4		4.1—		33.8	.....
Run-off, in inches		.027		.034		.026+		.772		1.47		.0052		.0035		.027+	.....
Run-off, per sq. mile		025		.031		.024+		.704		1.36—		0048		.0032		.025+	.....

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ARKALON STATION, CIMARRON RIVER.

This station was established by Mr. Arthur P. Davis, May 14, 1895, at the bridge of the Chicago, Rock Island & Pacific railroad, one-half mile north of Arkalon, Seward county, Kansas. This was the most accessible point at which the stream has a clearly defined channel above the diverting ditches. The observer is G. W. Seiver, the railroad agent at Arkalon. The gage is a vertical plank fastened to the pier of the bridge, under the north side. Measurements can be made from the bridge at high water, and at usual stages more conveniently done by wading. The bench mark is the top of the sill at the northwest corner of the windmill tower of the railroad water-tank. Its elevation is 14.43 feet. This station was discontinued October 31, 1896.

The following tables give the discharge measurements and the daily gage heights and discharges:

List of discharge measurements made on Cimarron river, at Arkalon, Kas.

No.	Date.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (square feet).	Mean velocity (feet per second).	Discharge (second feet).	Remarks.
	1895.							
1..	May 14	A. P. Davis.....	3	2.50	.....	1.31	17	Price meter.
2..	June 24	W. G. Russell...	3	2.70	13	1.30	16	" "
3..	July 23	" ...	3	7.00	178	1.79	319	" "
4..	Aug. 29	" ...	3	2.30	10+	1.55	16	" "
5..	Oct. 3	" ...	3	2.35	16	.98—	16	" "

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Daily mean gage height and discharge in second feet of the Cimarron river. Drainage area, 5,200 square miles.
Observer, G. W. SEIVER.

DAY.	July, 1895.		August, 1895.		September, 1895.		October, 1895.		November, 1895.		December, 1895.		January, 1896.		February, 1896.		DAY.
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	
1	2.90	24	6.00	170	2.55	19	2.30	16	2.50	18	2.40	17	2.50	18	2.50	18	1
2	2.90	24	5.35	112	2.40	17	2.30	16	2.40	17	2.40	17	2.50	18	2.50	18	2
3	2.90	24	4.00	48	2.40	17	2.30	16	2.40	17	2.40	17	2.50	18	2.50	18	3
4	3.30	31	3.85	43	2.40	17	2.30	16	2.40	17	2.40	17	2.50	18	2.50	18	4
5	4.15	52	3.60	37	2.40	17	2.40	17	2.40	17	2.40	17	2.50	18	2.50	18	5
6	3.95	46	3.00	28	2.45	17	2.40	17	2.40	17	2.40	17	2.50	18	2.50	18	6
7	3.60	37	2.80	22	2.50	18	2.40	17	2.40	17	2.40	17	2.50	18	2.50	18	7
8	3.35	32	2.75	21	2.40	17	2.40	17	2.40	17	2.40	17	2.50	18	2.50	18	8
9	2.90	24	2.70	21	2.40	17	2.40	17	2.40	17	2.40	17	2.50	18	2.50	18	9
10	2.80	22	2.70	21	2.40	17	2.40	17	2.40	17	2.40	17	2.50	18	2.50	18	10
11	2.90	24	2.70	21	2.40	17	2.40	17	2.40	17	2.40	17	2.50	18	2.50	18	11
12	2.80	22	2.70	21	2.40	17	2.40	17	2.40	17	2.40	17	2.50	18	2.50	18	12
13	2.70	21	2.70	21	2.40	17	2.40	17	2.50	18	2.40	17	2.50	18	2.50	18	13
14	2.10	14	2.70	21	2.40	17	2.40	17	2.40	17	2.40	17	2.50	18	2.50	18	14
15	2.70	21	2.70	21	2.40	17	2.40	17	2.40	17	2.40	17	2.40	17	2.50	18	15
16	2.70	21	2.70	21	2.40	17	2.40	17	2.40	17	2.40	17	2.50	18	2.50	18	16
17	2.60	19	2.70	21	2.40	17	2.40	17	2.40	17	2.40	17	2.50	18	2.50	18	17
18	2.60	19	2.75	22	2.40	17	2.40	17	2.40	17	2.40	17	2.50	18	2.50	18	18
19	2.85	23	2.80	22	2.35	16	2.40	17	2.40	17	2.45	17	2.50	18	2.50	18	19
20	4.60	69	2.80	22	2.30	16	2.40	17	2.40	17	2.50	18	2.50	18	2.50	18	20
21	5.15	98	2.80	22	2.30	16	2.40	17	2.40	17	2.50	18	2.50	18	2.50	18	21
22	4.90	84	2.70	21	2.30	16	2.40	17	2.40	17	2.50	18	2.50	18	2.50	18	22
23	6.45	221	2.70	21	2.30	16	2.40	17	2.40	17	2.50	18	2.50	18	2.50	18	23
24	7.50	436	2.70	21	2.30	16	2.40	17	2.40	17	2.50	18	2.50	18	2.50	18	24
25	7.10	340	2.70	21	2.30	16	2.40	17	2.40	17	2.50	18	2.50	18	2.50	18	25
26	7.25	372	2.70	21	2.30	16	2.40	17	2.40	17	2.50	18	2.50	18	2.50	18	26
27	7.45	422	2.75	21	2.30	16	2.40	17	2.40	17	2.50	18	2.50	18	2.50	18	27
28	8.15	659	2.70	21	2.30	16	2.40	17	2.40	17	2.50	18	2.50	18	2.50	18	28
29	8.15	659	2.50	18	2.30	16	2.40	17	2.40	17	2.50	18	2.50	18	2.50	18	29
30	7.60	465	2.30	16	2.30	16	2.50	18	2.40	17	2.50	18	2.40	17	.....	.....	30
31	6.85	288	2.55	18	.....	.....	2.50	18	.....	.....	2.50	18	2.40	17	.....	.....	31
Totals	.....	4,613	.....	937	.....	501	.....	525	.....	512	.....	539	.....	555	.....	522	.....
Mean	149—		30+		17—		17—		17+		17.4		18—		18		.....
Run-off, in inches	.033		.0066		.0036		.0037		.0036		.0039		.004		.0038—		.....
Run-off, per square mile	.028		.0057		.0032		.0033		.0032		.0033		.0034		.0034		.....

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Daily mean gage height and discharge in second feet of the Cimarron river. Drainage area, 5,200 square miles.
Observer, G. W. SEIVER.

Day.	March, 1896.		April, 1896.		May, 1896.		June, 1896.		July, 1896.		August, 1896.		September, 1896.		October, 1896.		Day.
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	
1	2.50	18	2.50	18	2.50	18	2.50	18	2.40	17	2.40	17	2.30	16	2.30	16	1
2	2.50	18	2.50	18	2.50	18	2.40	17	2.40	17	2.40	17	2.30	16	2.30	16	2
3	2.50	18	2.50	18	2.50	18	2.40	17	2.40	17	2.40	17	2.30	16	2.30	16	3
4	2.50	18	2.50	18	2.50	18	2.40	17	2.40	17	2.40	17	2.30	16	2.30	16	4
5	2.50	18	2.50	18	2.50	18	2.40	17	2.40	17	2.40	17	2.30	16	2.30	16	5
6	2.50	18	2.50	18	2.50	18	2.40	17	2.40	17	2.40	17	2.30	16	2.30	16	6
7	2.50	18	2.50	18	2.50	18	2.40	17	2.40	17	2.40	17	2.30	16	2.30	16	7
8	2.50	18	2.50	18	2.50	18	2.40	17	2.30	16	2.40	17	2.30	16	2.30	16	8
9	2.50	18	2.50	18	2.50	18	2.40	17	2.30	16	2.40	17	2.30	16	2.30	16	9
10	2.50	18	2.50	18	2.40	17	2.40	17	2.30	16	2.40	17	2.30	16	2.30	16	10
11	2.50	18	3.00	26	2.40	17	2.40	17	2.30	16	2.40	17	2.30	16	2.30	16	11
12	2.50	18	4.15	52	2.50	18	2.40	17	2.30	16	2.40	17	2.30	16	2.30	16	12
13	2.50	18	3.00	26	2.50	18	2.40	17	2.30	16	2.40	17	2.30	16	2.30	16	13
14	2.50	18	2.80	22	2.50	18	2.40	17	2.30	16	2.40	17	2.30	16	2.30	16	14
15	2.50	18	2.70	21	2.50	18	2.40	17	2.85	23	2.40	17	2.30	16	2.50	18	15
16	2.50	18	2.60	19	2.50	18	2.40	17	2.65	20	2.35	16	2.30	16	2.50	18	16
17	2.50	18	2.60	19	2.50	18	2.40	17	2.50	18	2.30	16	2.30	16	2.50	18	17
18	2.50	18	2.60	19	2.50	18	2.40	17	2.50	18	2.30	16	2.30	16	2.50	18	18
19	2.50	18	2.50	18	2.50	18	2.30	16	2.50	18	2.30	16	2.30	16	2.50	18	19
20	2.50	18	2.50	18	2.50	18	2.30	16	2.50	18	2.30	16	2.30	16	2.50	18	20
21	2.50	18	2.50	18	2.50	18	2.40	17	2.50	18	2.30	16	2.30	16	2.50	18	21
22	2.50	18	2.40	17	2.50	18	2.40	17	2.50	18	2.30	16	2.30	16	2.50	18	22
23	2.50	18	2.40	17	2.50	18	2.40	17	2.50	18	2.30	16	2.30	16	2.50	18	23
24	2.50	18	2.40	17	2.50	18	2.40	17	2.50	18	2.30	16	2.30	16	2.50	18	24
25	2.50	18	2.40	17	2.50	18	2.40	17	2.50	18	2.30	16	2.30	16	2.50	18	25
26	2.50	18	2.50	18	2.50	18	2.40	17	2.50	18	2.30	16	2.30	16	2.50	18	26
27	2.50	18	2.50	18	2.50	18	2.40	17	2.50	18	2.30	16	2.30	16	2.50	18	27
28	2.50	18	2.50	18	2.50	18	2.40	17	2.45	17	2.30	16	2.30	16	2.50	18	28
29	2.50	18	2.50	18	2.50	18	2.40	17	2.40	17	2.30	16	2.30	16	2.50	18	29
30	2.50	18	2.50	18	2.50	18	2.40	17	2.40	17	2.30	16	2.30	16	2.50	18	30
31	2.50	18	.....	.....	2.50	18	.....	.....	2.45	17	2.35	16	.....	.....	2.50	18	31
Totals	.....	558	.....	596	.....	556	.....	509	.....	540	.....	511	.....	480	.....	528	.....
Mean	18		19.9—		18—		17—		17.4		16.5		16		17		.....
Run-off, in inches	.004		.0042		.004		.0036		.0038		.0036		.0034		.0037		.....
Run-off, per square mile	.0034		.0038		.0044		.0033		.0033		.0032		.0031		.0033		.....

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TABLE showing the mean monthly flow in cubic feet per second of each of the rivers mentioned in this report.

MONTH.	Smoky Hill at Ellsworth.	Saline at Beverly.	Solomon at Beloit.	Republican at Junction City.	Arkansas at Hutchinson.	Cimarron at Arkalon.	Medicine at Kiowa.
1895.							
July	44,582	17,802	68,256	55,814	119,304	4,613	5,270
August	5,750	3,127	50,493	98,942	84,069	937	917
September	1,316	1,153	4,679	16,265	11,252	501	591
October	567	843	868	7,729	1,745	525	451
November	526	975	684	8,458	1,293	512	1,476
December	523	1,030	3,541	12,163	2,202	539	806
Totals	53,264	24,930	128,521	199,371	219,865	7,627	9,511
1896.							
January	776	1,622	2,720	13,889	13,192	555	1,437
February	762	1,476	2,995	21,917	10,074	522	1,218
March	546	1,509	2,903	15,624	4,735	558	1,031
April	3,904	4,535	49,725	42,407	3,859	596	1,189
May	1,914	9,692	13,313	65,843	1,666	556	1,008
June	9,377	68,730	25,547	41,101	4,927	509	26,956
July	7,138	8,859	38,365	114,008	7,786	540	55,301
August	3,553	3,305	10,964	27,673	2,125	511	198
September	2,164	1,739	3,911	20,011	795	480	122
October	1,659	8,068	9,347	14,723	1,625	528	1,049
November	1,631	2,249	2,293	19,651	2,370	.....	.....
December	1,043	1,781	2,855	25,122	1,600	.....	.....
Totals	87,731	138,495	293,459	621,335	274,619	12,945	99,020
Average	4,874	7,694	16,303	34,519	15,256	809	6,188

The Republican river, during the 18 months ending December 31, 1896, had a flow of 621,335 second feet or 1,240,000 acre feet, or an average per month of 34,519 second feet or 69,000 acre feet, and 828,000 acre feet per year, and assuming that one acre foot would irrigate one acre of land, the run-off of the Republican river would in one year irrigate 828.000 acres of land, or 32 acres of each section in its entire drainage area.

The Solomon river, during the 18 months ending December 31, 1896, had a flow of 293,459 second feet or 586,000 acre feet, or an average per month of 16,303 second feet or 32,500 acre feet, and 390,000 acre feet per year, and assuming as before that one acre foot will irrigate one acre of land, the run-off of the Solomon river would in one year irrigate 390,000 acres, or 70 acres of each section of its entire drainage area. The bed of this stream is muddy, sandy, and gravelly, and does not carry much water below the soil. The banks of this stream are high, but the water could be taken out by pumps, or dams and ditches, but more cheaply with the former.

The Saline river, during the 18 months ending December 31, 1896, had a flow of 138,495 second feet or 276,800 acre feet, or an average per month of 7,694 second feet or 15,200 acre feet, and 182,400 acre feet per year, which would irrigate 182,400 acres, or 66 acres on each section of its entire drainage area. The bed of this stream is muddy and sandy, but does not likely carry a large amount of water, and the banks are high at Beverly and for many miles west, but gradually lower, and water could be taken out with greater economy with pumps than with dams and ditches.

The Smoky Hill river, during the 18 months ending December 31, 1896, had a flow of 87,731 second feet or 175,000 acre feet, or an average per month of 4,874 second feet or 9,700 acre feet, and 116,400 acre feet per year, which would irrigate 116,400 acres, or 14 acres on each section of its entire drainage area. The bed of this stream is very sandy, and carries quite an amount of water in the sand. The

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banks are not too high for pumping economically, and water could be taken out by dams and ditches at a reasonable cost.

The Arkansas river, during the 18 months ending December 31, 1896, had a flow of 274,619 second feet or 548,000 acre feet, or an average per month of 15,256 second feet or 30,500 acre feet, and 366,000 acre feet per year, which would irrigate 366,000 acres, or 10.8 acres on each section of its entire drainage area, or 39 acres to each section of its Kansas drainage. The banks of this river are very low and sandy, and the bed is very sandy and changeable, and carries a large amount of water in it. The water of this stream can be utilized by pumps or ditches, and cheaply.

The Cimarron river, during the 16 months ending October 31, 1896, had a flow of 12,945 second feet or 25,890 acre feet, or an average per month of 809 second feet or 1,600 acre feet, and 19,200 acre feet per year, which would irrigate 19,200 acres, or four acres on each section of its entire drainage area. The banks of this stream are low and sandy, and amount of water is small but very regular. The water could be taken out by ditches or pumps, and at no great expense.

The Medicine river, during the 16 months ending October 31, 1896, had a flow of 99,020 second feet or 198,040 acre feet, or an average per month of 6,190 second feet or 12,380 acre feet, and 148,000 acre feet per year, which would irrigate 148,000 acres, or 113 acres on each section of its entire drainage area. The banks of this stream are very low, and the bed of the stream is very sandy and carries much water in it. The water could be taken out of this stream either by ditch or any form of pump, and with small expense.

The total run-off of all the rivers above amounts to 613,488 second feet, which is equal, in round numbers, to 1,226,000 acre feet per year. If we assume that 12 inches of water is sufficient to irrigate land, in addition to the rainfall we now have, then each acre foot will irrigate one acre of land, and this is the assumption in the results given in this report. In this state, west of the ninety-eighth meridian, there are about 44,000 square miles; could this water be distributed uniformly over this section, and all utilized, it would irrigate 28 acres of each section therein. In this assumption I have left out the Republican river, as it is nearly all in Nebraska and Colorado; now, quite a large amount of land in this section cannot be irrigated in any event, profitably, owing to its location, and deducting this amount, which probably reaches 25 per cent., then we have 37 acres to each section. As the adjacent bottom lands are the most accessible, and would be first irrigated, it will be well to see how much water there is for this land. There seems to be enough water to irrigate the bottom lands along the streams, and quite a large proportion of it at no great expense.

The Arkansas and Cimarron rivers would furnish a less amount of water than any of the others; a very large portion of the former's water is taken out in Colorado and this will be increased in the future, it may be to the entire amount at the state line, except the large floods.

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Underground Water.

By D. M. FROST.

The great problem of a water supply for irrigation purposes on the western plain of Kansas is the easiest thing in the world conceived of and the hardest to bring about. The student who has followed this special line of of investigation finds many obstacles in his way that must be overcome, while at the same time he finds much to encourage him in continuing the work. Kansas is a very prolific field in this line, and we may say that it is as large as it is prolific, embracing as it does fully one-half of the entire state: or, to be more exact, all that portion of the state lying west of the ninety-eighth meridian, embracing 43,200 square miles or 27,648,000 acres, all of which is usually denominated as the arid or semiarid portion of our state, upon which lands an artificial application of water must be given to insure a crop each and every year.

But it must not be assumed that all of this vast expanse of country can be successfully irrigated with our present or our future available water supply, as we cannot hope for this to be done under the best possible conditions. Yet when we recount what has been done, or is being done now, in the line of applying water by artificial means to our arid lands, then we may be the better enabled to judge as to its success or failure, and whether it would be wise or unwise for the state and federal governments to continue to aid in this direction. But this does not rest entirely on what has already been accomplished in this line, any more than it would for us to say that the future possibilities may be tenfold greater than that which has already been realized. The two propositions must go together, since there has been a constant and continuous advancement along the line of the principle followed, uncovering more water day by day as the investigation progressed, likewise adding more acres to our cultivated fields, clearly indicating that we have taken the first or initiatory step in the great work yet to follow, and that the future investigations and developments will bring to light possibilities as yet unthought of and unknown. There are in the state at this time about 1,200 miles of irrigating canals or ditches, all of which have been constructed since 1880, at one time or another irrigating upwards of 200,000 acres of land. Eight hundred miles of these irrigating canals are located in the counties of Hamilton, Kearny, Finney, Gray, and Ford, along the Arkansas river, from which they derive their water whenever water flows in the river. These ditches have been the means of bringing under a high state of cultivation and productiveness 124,000 acres in the five counties named.

Since 1892, the surface flow of the Arkansas river has gradually failed, until in the year 1896 there was scarcely any flow east of the Colorado line; not because there was any diminution in the water supply at the sources of the river, but on account of the increase in the number and carrying capacity of ditches constructed in Colorado, which absorbed all the waters and thereby left Kansas ditches unsupplied. There can, perhaps, be no serious objection to this, since Congress accorded to the state of Colorado that right when she was admitted into the sisterhood of states, but it leaves our ditch owners and farmers in a very precarious condition on this side of the Colorado line.

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To supply these ditches with water, and in turn water the lands they cover, another system must be thought out and developed; and since the surface flow of water from this particular river cannot longer be depended upon, the subsurface, or the so-called underflow waters, must be used, provided a sufficient amount of water can be found and made available. The amount of this water is generally considered to be very great.

During the summer of 1896, the following experimental pumping tests were made at and near Garden City, in the Arkansas valley, where water is obtained within 8½ feet from the surface. The water was drawn from the sands and gravel through a sand point 6 inches by 10 feet in length, attached to a six-inch pipe penetrating the water-bearing sand and gravel 36 feet in depth, with a No. 2 centrifugal pump operated by steam power, suction pipe 2½ inch, discharge pipe two-inch, depth to water 8½ feet, or water stood in six-inch pipe, into which 2½-inch suction pipe was admitted, to the depth of 20 feet from surface of ground, water standing at 8½ feet below land level: water lowered during time pump was running to the depth of 18 feet. Amount of water drawn was 245 gallons per minute—water lift from top of reservoir embankment over which it was discharged into reservoir, 22 feet—14,700 gallons per hour, of 147,000 gallons for the 10 hours' test, with no sign of any diminution in the supply.

Test No. 2 was made with a No. 3 centrifugal pump and open well. Water drawn from sand and gravel, like condition as No. 1. Four-inch suction and 3½ discharge, 16½ feet lift; water pumped, 625 gallons per minute, or 37,500 gallons per hour, or 375,000 gallons per day of 10 hours.

TABULATED CENTRIFUGAL-PUMP TEST.

Pump No.	Suction pipe.	Discharge pipe.	Gallons per minute.	Gals. per day, 10 hours.
No. 2	2½ inches.	2 inches.	245	147,000
No. 3	4 inches.	3½ inches.	625	375,000

The Hutchinson Packing Company, at Hutchinson, in the Arkansas valley, and close to the 98th meridian, has had occasion to use a large amount of water. In answer to inquiries concerning the methods used to lift it from the underflow sand and gravel, and the quantity raised, Mr. Walter H. Underwood, manager, writes as follows:

"We have in operation three No. 6 Van Wie centrifugal pumps, eight-inch suction and six-inch discharge, running 780 revolutions per minute, and from close estimates and by the work we are doing we figure that we are pumping 1,300 gallons per minute with each pump.

"The duty of these pumps is to force water 58 feet high into a vacuum condenser. Our 25-inch vacuum which we carry pulls this water about 26 to 28 feet, making the total lift on the pumps 30 to 32 feet.

"The first pump we put in operation we had four 8-inch points connected together in one main line to the pump. Our suction was 12 feet. This work was so exceedingly hard on the pumps that we were bothered continually with the pump heating and belts breaking from the excessive strain. The next pump we put in we put in six 8-inch points for suction, and the third one has eight points. These points are connected in gangs, and every other one is to a different depth—for instance, we put the first point at 20 feet, the next one at 45 to 50 feet, the next one at 20 to 25 feet, and so on, so as to get

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the water from different veins—provided we get the water from veins, which I very much doubt.

"We used to think that we had from two to four strata of water, as in putting down the points we would go through a bed of clay from two to four feet thick. But our experience has been, in putting down 18 points, that we find the clay at different depths, which leads us to believe that it is not a stratum but simply boulders.

"After the points are down we connect up the pump and pull as hard as possible to draw out all the quicksand in the vicinity, and run about a week. We then take the plug out of the top of the line and sand-bucket the points thoroughly. This operation is performed, say three times during the next two or three months, and by that time all the quicksand that will naturally go to the points has been pumped out.

"I forgot to state above that the first pump we put in, having only four points, was so unsatisfactory on account of the wear and tear that we put in an open well, 20 feet deep and 16 feet in diameter, made of brick laid in cement. We then put in 12 small points, which we made of different size scrap pipe, from two to four inches in diameter, and have a 6-inch suction line running into this well and also to the four 8-inch points, with valves, so that we can take supply from either point.

"The water naturally stood about 12 feet below the pump, and we figured that we were lifting this water too much for the good of the machinery. So that we built a large pond, digging it out 16 feet deep down to the coarse gravel. We then run our waste water from the condensers into this pond, with the idea that the water would percolate back through the sand and raise the water in the vicinity of the points which are adjacent to the pond. Our men report that the water now naturally stands in all the points four or five feet higher than it used to, now making the suction on our pumps seven or eight feet instead of 12 feet.

"The 8-inch points are of our own manufacture, being bored full of ¼-inch holes for probably 10 feet in length, and then covered with perforated brass with holes about 1-16 of an inch. Before we wrapped the brass around the points we wrapped small wire over the section of pipe punched full of holes to keep the brass away from the pipe, thereby getting all the available open space instead of simply having an opening wherever the holes in the brass might come over the holes bored in the pipe. These points we drove down with our well machine, sand-bucketing out as we went down, and let them remain in the coarse gravel we found. The bottom is left open, and after sand-bucketing as stated above the point probably fills up with coarse gravel, but it being of such a coarse nature does not stop the flow of water.

"I forgot to state that the points are connected with the main line with a cross so that we can take out the plug at any time and sand-bucket the point out."

Mr. H. V. Hinckley, of Topeka, consulting civil engineer, an eminent authority on engineering problems, writing us on the subject of the availability of the Arkansas underflow for irrigation purposes, says:

"From tests which I have made upon numerous wells, and from over a thousand experiments upon flow of water in sands and gravel, I am safe in stating that wells properly designed will furnish any desired amount of water, from 1,000 to 10,000,000 gallons a day. As to the availability for irrigation, it is only a question of cost. If wells were to be put in thickly there would some time be a question of permanency of supply, but that is not a

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present problem. The underflow can be put on top of the ground at from $10 to $25 an acre, first cost, by pumps for individual tracts or by gravity for corporations."

The many thousand cubic feet of water per second of time that flowed through the channel of the Arkansas river years ago unmolested and undisturbed is to-day diverted from its channel and course and made to do duty for the Colorado ranchman and farmer, being carried to the high plains of Colorado, where it is absorbed into the soil, and all that is not absorbed by evaporation or plant growth is finding lodgment by percolation into the sands of the plain above Kansas, to which state it naturally tends, and, since there is no other avenue of escape, must come. This brings us to a source of supply rarely thought of, much less considered—one that cannot be taken from the people of this state, since it has passed beyond the control of the people of Colorado. The process, though slow it may be, is bringing the water nearer to the surface year after year, which is the history and experience of all irrigated countries, and Kansas will prove no exception to the rule.

The estimated acreage of valley lands along the line of the several rivers and streams within the territory under consideration is about as follows:

Along the two Cimarron rivers	650	square	miles.
Along the Arkansas river	1,500	"	"
Along the Pawnee and tributary	100	"	"
Along the Walnut and tributary	125	"	"
Along the Smoky and tributary	150	"	"
Along the Saline	125	"	"
Along the Solomon and tributaries	350	"	"
Along the Beaver and two Sappas	150	"	"
Along the Prairie Dog	100	"	"
Total	3,250	square	miles.

Or 2,080,000 acres of land that ultimately may be brought under a high state of cultivation, by some well defined system known, such as the gravity flow or gravity system, which would dispense with pumps and power to operate them, a very great saving in the securing water for irrigation purposes, as compared to the pumping system, no matter what power might be utilized. A conservative estimate of our water supply from seven of the principal rivers flowing through the state, which empty their waters into the Missouri and Mississippi rivers, as is shown by W. G. Russell, assistant hydrographer, U. S. Geological Survey, very clearly indicates that we are losing annually enough water to irrigate 2,572,336 acres of land a foot in depth, which, added to the valley or bottom land of the rivers named, would give us a total of 4,591,136 acres; to this may be added the lands that ultimately will be covered by the individual pumping system or individual irrigation plants, which will at this time add a trifle over 30,000 acres, and would make the grand total of 4,621,136 acres; nearly 5,000,000 acres of land out of the 27,648,000 acres embraced within the territory under consideration.

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Weather Report.

By D. M. FROST.

Through the courtesy of George T. Todd, official in charge of the United States signal station at Dodge City, Kas., this Board is supplied with the interesting and important data of the monthly precipitation, monthly mean temperature, prevailing wind direction, average wind velocity, monthly percentage of sunshine, and annual percentage of miles and time for each direction; all of which tables are of the utmost importance when considered in connection with agricultural pursuits, and especially so in connection with the lifting of water for irrigation purposes by wind power. Therefore the tables of wind velocity and wind direction are important and worthy of careful study. The data on precipitation is of no less importance, since it so clearly indicates the source and yearly average of the water supply of the great plains country. This report indicates that the annual average of rainfall for 21 years last past has been 19.96 inches per annum. It further shows that over one-half of this annual rainfall fell during the months of May, June, July, and August, the four growing months of the year. It further indicates that a little over one-half of the remainder has fallen in the months of March, April, and September, during the planting and seeding season. The residue or remainder of this annual precipitation fell in the months of January, February, October, November, and December, the winter months, which accounts for the dry and open winters on the plains. The table giving the monthly mean temperature is as important as it is interesting, and well worthy of a place in the report; likewise the report on annual percentage of sunshine; all of which data is herewith given.

Dodge City, Kas., December 10, 1896.

Hon. D. M. Frost, Garden City, Kas.:

Dear Sir—Enclosed herewith please find data as requested in your letter of the 5th instant.

The data enclosed is as follows: Monthly precipitation since opening of station.

Monthly mean temperature since opening of station.

Prevailing (monthly) wind direction since opening of station.

Average hourly wind velocity for the months since opening of station.

Monthly percentage of sunshine for the past seven years (monthly).

Annual percentage of miles and time for each direction since 1890. (monthly).

This data is complete to date.

Very respectfully,

GEORGE T. TODD, Official in Charge.

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PRECIPITATION AT DODGE CITY, KAS.

YEAR.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total for year.
1874	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.27	0.24	0.05	.....
1875	0.12	0.10	0.04	0.71	2.26	0.73	3.28	2.06	1.32	0.06	T.	0.09	10.77
1876	T.	0.05	3.59	0.16	1.15	2.53	2.26	1.03	2.13	1.00	1.35	0.15	15.40
1877	0.18	0.56	0.25	3.38	4.96	3.92	1.79	4.09	0.50	3.34	0.56	4.36	27.99
1878	0.21	1.13	1.01	1.06	4.63	2.19	1.61	4.48	0.76	0.09	0.60	0.19	17.96
1879	0.87	0.08	0.17	0.40	0.90	4.40	3.90	3.75	0.80	T.	0.04	0.12	15.43
1880	T.	T.	0.01	0.11	3.33	1.59	4.00	5.17	0.32	1.42	2.43	0.03	18.44
1881	0.15	1.63	0.50	2.38	12.82	1.77	5.06	2.86	3.13	2.19	0.95	0.61	33.55
1882	0.52	0.22	0.24	0.68	3.87	1.51	3.04	1.07	0.15	1.62	0.11	0.11	13.14
1883	0.44	1.42	0.42	2.40	5.41	4.31	2.61	5.66	1.32	3.32	0.12	1.07	28.50
1884	0.08	0.28	1.91	1.07	4.47	7.67	6.40	4.82	0.23	1.50	0.83	1.10	30.36
1885	0.52	0.47	0.75	1.39	4.07	2.02	6.03	1.80	3.48	1.06	0.36	1.76	28.71
1886	1.82	0.46	1.50	1.90	0.40	5.47	2.07	2.46	2.33	0.45	0.24	0.25	19.35
1887	0 07	0.53	0.17	2.46	3.69	4.00	1.00	2.28	0.14	0.48	0.35	0.54	15.71
1888	0 23	0.73	0.93	4.08	2.86	5.16	4.07	3.00	0.78	0.81	0.06	0.23	22.94
1889	1.69	0.34	1.38	2.12	1.54	3.43	2.02	2.14	0.86	2.88	0.77	T.	19.17
1890	0.42	0.39	0.05	2.90	1.19	1.00	0 22	3.45	0 57	0.89	0.50	0.14	11.72
1891	0.98	0.27	3.32	2.76	3.36	6.27	5.16	1.36	4.56	3.33	0.12	0.85	32.34
1892	0.25	1 01	2.62	0.40	3.23	3.34	0.66	4 69	1.04	0.73	0.31	1.38	19.66
1893	0.02	0.34	T.	0.04	1.31	0.76	3.32	1.82	1.74	0.25	0.42	0.10	10.12
1894	0.04	1.03	0.40	1.88	0.95	2.80	2.05	0.15	2.03	0.62	0.03	0.62	12.60
1895	0.58	2 26	1.31	0.91	0.97	5.32	4.84	2.42	0.06	1.09	0.34	0.21	20.31
1896	0.49	T.	0 25	5.50	1.13	1.98	5.41	0.75	1.06	2.45	0.34	.....	.....
Sums	9.68	13.30	20.85	38.6	68.50	72.17	70.80	60.79	29.31	29.85	11.07	13.96	419.07
Means	0.44	0.60	0.95	1.76	3.11	3.28	3.22	2.76	1.33	1.30	0.48	0.64	19.96

MONTHLY MEAN TEMPERATURE AT DODGE CITY, KAS.

YEAR.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly mean temp.
1874	.....	.....	.....	.....	.....	.....	.....	.....	.....	58.2	38.0	35.2	.....
1875	13.0	29.1	39.7	47.8	65.0	73.9	75.6	74.6	69.1	57.2	41.1	42.2	52.4
1876	36.8	41.9	36.0	56.7	64.4	70.6	79.7	77.8	67.2	53.5	40.4	24.8	52.2
1877	24.4	38.6	44.3	51.0	63.9	71.0	78.1	77.1	69.4	53.2	39.8	40.4	54.3
1878	33.6	39.5	50.2	55.8	61.6	70.6	79.6	79.2	67.6	55.8	44.6	23.4	55.1
1879	23.9	33.8	48.2	56.9	69.3	76.2	80.8	76.6	68.0	59.5	41.4	26.4	55.1
1880	38.2	35.8	41.0	54.8	69.3	75.3	76.2	75.0	66.4	52.2	25.6	24.7	52.9
1881	20.0	27.0	41.0	54.6	64.9	77.5	77.0	80.1	69.0	57.5	38.7	37.4	53.7
1882	31.6	39.2	48.2	54.2	58.0	74.1	75.9	75.1	69.0	58.3	41.6	32.7	54.8
1883	22.4	26.6	40.6	54.1	61.9	71.5	77.4	73.0	65.2	50.6	42.4	35.2	51.7
1884	24.4	28.0	42.2	49.8	59.8	71.4	77.6	72.2	71.1	58.8	42.0	21.4	51.6
1885	18.0	26.5	42.3	55.7	60.0	72.6	77.9	74.8	67.6	52.6	46.4	37.1	52.6
1886	16.9	35.8	40.6	51.9	63.9	72.0	79.4	79.7	68.6	59.8	39.2	29.9	53.6
1887	27 5	31.2	46.4	54.8	66.0	74.5	79.2	75.6	69.0	54.3	42.8	29.4	54.2
1888	23.3	39.3	37.4	57.5	61.5	73.6	80.0	74.4	67.8	55.0	41.1	38.4	54.1
1889	28.9	29.0	45.8	56.6	63.7	69.8	77.5	76.9	66.3	55.6	37.4	44.6	54.3
1890	27.2	32.4	42.5	54.2	63.6	75.0	82.4	76.4	65.2	55.5	44.4	38.8	54.8
1891	28.8	32.0	33.8	55.4	61.6	69.6	73.8	74.0	68.4	55.2	40.9	37.4	52.6
1892	28.9	34.7	36.5	51.8	57.8	71.9	77.0	76.0	69.8	56.2	42.4	25.6	52.4
1893	34.0	31.0	42.2	53.5	60.4	75.0	79.4	73.8	70.4	56.8	40.4	38.6	54.6
1894	30.8	24.3	46.1	57.6	64.9	73.4	78.5	75.9	68.9	59.4	44.4	34.4	54.9
1895	29.6	25.4	42.9	57.0	64.8	70.0	74.0	75.6	72.7	52.8	41.4	33.8	53.1
1896	36.4	39.2	40.0	59.9	68.4	76.2	77.6	79.4	66.2	54.2	38.0	.....	.....
Sums	588.6	720.3	927.9	1,201.6	1,399.7	1,605.7	1,714.6	1,673.2	1,502.9	1,282.2	934.4	731.8	1,125.0
Means	27.2	32.7	42.2	54.6	63.6	73.0	77.9	76.1	68.3	55.7	40.6	33.3	53.6

PERCENTAGE OF SUNSHINE (MONTHLY) AT DODGE CITY, KAS.

YEAR.	Jan. %	Feb. %	Mar. %	Apr. %	May. %	June. %	July. %	Aug. %	Sept. %	Oct. %	Nov. %	Dec. %	Av. for year.
1890	.....	.....	.....	48	61	66	73	71	62	76	.....	69	.....
1891	.....	.....	49	66	61	53	62	78	69	79	54	62	.....
1892	65	50	52	60	49	75	67	81	82	65	64	47	63
1893	70	62	79	75	68	81	75	72	74	89	73	67	74
1894	68	66	74	74	72	77	74	77	76	86	79	71	74
1895	51	58	72	67	69	65	63	75	84	77	69	66	68
1896	55	75	69	68	63	80	63	78	66	72	62	.....	.....

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PREVAILING WIND DIRECTION, DODGE CITY, KAS.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	For the year.
1875	N	N	N	N	N	S	SE	S	S	NW	N	W	N
1876	SE	SE	N	N	E	SE	E	SE	SE	SW	N	N	SE
1877	NW	N	N	N	S	S	S	S	S	N	N	S	S
1878	N	N	N	N	S	S	S	S	S	S	N	N	S&N
1879	N	N&S	NE	S	S	S	S	S	S	S	S	N	S
1880	N	NW	NW	N	S	S	S	S	S	N	N	N	N&S
1881	N	N	N	NE	S	SE	SE	S	S	S	N	N&S	N
1882	S	S	S	S	N	S	S	S	S	S	N	N	S
1883	NW	NW	N	SW	SW	SW	SW	SE	SE	SE	SE	NW	SW &SE
1884	W& NW	NW	SE	NW	SE	SE	SE	SE	SE	SE	NW	NW	SE
1885	NW	W	NW	SE	SE	SE	SE	SE	SE	NW	NW	NW	SE
1886	NW	NW	NW	S	S	SE	S	S	S	SE	NE	SE	SE
1887	S& SE	SE	N	SE	SE	SE	SE	S	SE	NE	NE	NE	SE
1888	NE	NE	NE &S	S	SE	SE	SE	SE	S	S	S	N&S	S
1889	W	NE	NE	SE	N	S	S	S	S	N	N	S	S
1890	N&S	N	NE	S	NE	S	S	S	S	N	N	N	S
1891	NW	SE	NW	S	S	S	S	S	S	S	NW	NW	S
1892	NW	NW	NW	NW	N	SE	SE	SE	SE	SE	SE	SE	SE
1893	NW	NE	SE	NE	NE	SE	SE	SE	SE	SE	SE	NW	SE
1894	SE	NW	SE	SE	SE	SE	SE	S	S	SE	NE	NW	SE
1895	NE	NW	S	SE	S	SE	S	SE	S	SE	NW	NW	SE
1896	SE	NW	NE	S	S	SE	SE	SE	SE	SE	SE	.....	SE
Prevailing,	NW	NW	N	S	S	SE	S&SE	S	S	SE	N	N	SE

AVERAGE HOURLY WIND VELOCITY AT DODGE CITY, KAS.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Av. for year.
Av. for 10 years, 1874 to 1885	10.9	11.5	14.0	14.9	14.5	13.3	12.6	11.1	12.4	12.0	10.4	10.3	12.3
1885	11.4	10.8	10.5	15.7	11.8	13.4	11.7	10.6	12.7	10.9	9.2	9.7	11.5
1886	11.6	10.9	13.0	15.3	11.2	10.8	7.2	10.0	10.5	10.1	8.4	8.6	10.6
1887	9.8	11.0	10.3	11.9	10.3	10.6	9.2	10.1	10.9	8.8	8.4	9.8	10.1
1888	8.4	9.5	12.5	14.4	14.5	16.0	12.1	9.8	9.2	9.5	10.0	10.2	11.3
1889	9.8	9.5	10.1	11.2	14.2	11.4	12.2	14.6	11.5	9.7	8.1	11.0	11.1
1890	9.9	10.8	12.4	12.8	13.9	15.2	11.6	10.8	9.2	10.2	9.4	9.4	11.3
1891	10.3	13.1	13.7	13.3	12.9	14.0	11.7	11.1	14.5	11.0	10.8	12.2	12.4
1892	9.7	9.2	12.8	16.3	12.8	13.6	11.9	10.3	11.2	10.4	10.5	8.4	11.4
1893	9.8	12.2	13.2	15.3	14.2	15.1	13.9	10.8	12.1	11.2	11.3	11.0	12.5
1894	9.5	10.8	14.3	14.9	13.2	15.1	11.0	9.5	12.4	12.3	10.3	10.8	12.0
1895	10.2	10.0	12.8	15.5	14.6	12.4	10.4	10.2	15.0	9.2	10.6	10.4	11.8
1896	9.6	10.6	13.0	17.0	15.3	12.6	11.1	11.0	10.4	9.8	10.3	.....	.....
Av. for 22 years,	10.4	11.2	13.1	14.2	13.8	13.3	11.9	10.9	12.0	11.2	10.1	*10.6	*11.9

* Average for 21 years.

ANNUAL PERCENTAGE OF MILES AND TIME FOR EACH DIRECTION.

Year.	Wind — percentage of miles and percentage of time from (By double or triple self-register.)																Calm.	
	N.		NE.		E.		SE.		S.		SW.		W.		NW.			
	Miles.	Time.	Miles.	Time.	Miles.	Time.	Miles.	Time.	Miles.	Time.	Miles.	Time.	Miles.	Time.	Miles.	Time.	Miles.	Time.
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
1891	12	12	9	9	3	3	8	8	39	31	9	8	2	3	16	17	3	11
1892	11	12	12	15	3	4	34	29	17	13	5	5	3	5	15	16	0	1
1893	8	9	15	17	3	5	38	33	11	9	8	7	3	4	15	15	0	0
1894	10	12	13	15	3	5	27	26	24	17	7	7	2	4	13	13	0	0
1895	13	15	13	16	2	4	23	23	29	20	4	5	2	3	14	13	0	1

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Artesian Well Tests, Etc.

By D. M. FROST.

Made in Meade and Finney counties, with No. 2 centrifugal pump and steam power, showing two important points: Accelerated flow with pump, and increased natural flow after pump was detached.

Name of owner.	Location.	Depth of well, in feet.	Flow in gallons before test.	Flow in gallons during test.	Flow in gallons after test.	Size of pipe.
G. O. Vick	N. E. ¼, 29-30-27	165	45	110	55	2½
G. O. Vick	N. E. ¼, 29-30-27	130	8	48	12	2½
Wm. Colter	S. W. ¼, 4-23-33	93	1	21	6	2

From the three wells so tested there was a vast amount of sand brought up: especially was this the case with the two first, which are located in Meade county. The well in Finney county being the least in flow of the wells tested, which gave up very little sand. The increased flow after the pump was detached was doubtless owing to the fact of the removal of the fine sand from the inlet point to the pipe, thus giving an increased flow of water.

WIND PRESSURES.

The following table of wind pressure commonly used is inserted for convenient reference:

Description of Wind.	Velocity.		Pressure. Per square foot, in pounds.
	Miles per hour.	Feet per minute.	
Hardly observable	1	88	.005, or about ⅛ of an ounce.
Just perceptible	2	176	.02, " ½ "
	3	264	.045, " ¾ "
Light breeze	4	352	.08, " 1¼ "
Gentle, pleasant wind	5	440	.125, " 2 "
Fresh breeze	10	880	.5, " 8 "
Brisk blow	15	1,320	1.125, " 1 lb. 2 ounces.
Strong wind	20	1,760	2.
Very strong wind	25	2,200	3.125.
High wind	30	2,640	4.5.
	35	3,080	6.125.
Very high wind	40	3,520	8.
Gale	50	4,400	12.5.
Violent gale	60	5,280	18.
Hurricane	80	7,040	32.
Tornado	100	8,800	50.

From the above table it will be seen that, with a velocity of four or five miles per hour, the pressure is less than two ounces per square foot of wind surface, and that its effective force depends entirely on the velocity.

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AVERAGE ANNUAL PRECIPITATION CHART, KANSAS.

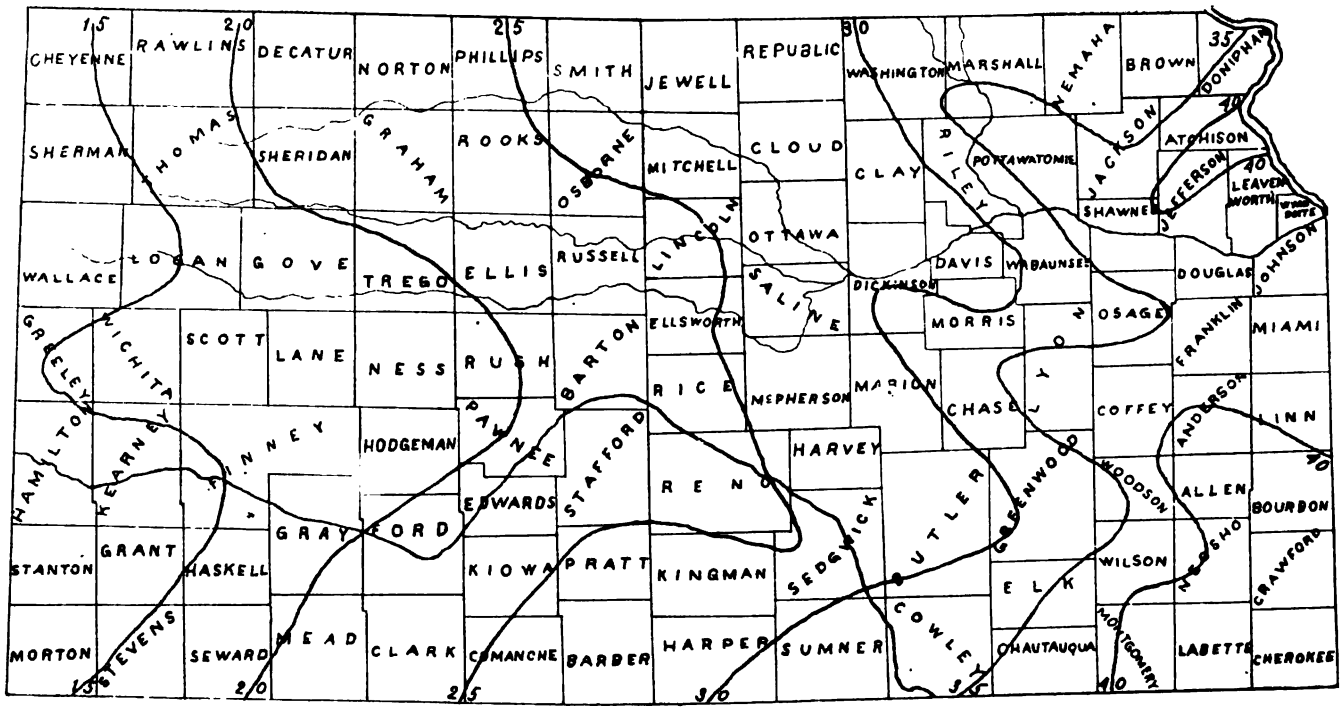

Fig. 20.

A chart showing the average annual rainfall and melted snow in Kansas; the lines connecting places having equal amounts. Copy of enlarged chart was supplied by T. B. Jennings, section director, Kansas section U. S. Weather Bureau.

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SAND AND GRAVEL WATER ABSORPTION.

A cubic foot of coarse gravel will absorb 26 per cent. of water.
A cubic foot of medium coarse gravel will absorb 27 per cent. of water.
A cubic foot of fine sand will absorb 31½ per cent. of water.
A cubic foot of quicksand will absorb 37½ per cent. of water.

These tests were made with kiln-dried sand and gravel, and made for the sole purpose of learning the quantity of water a cubic foot of sand or gravel would absorb or was capable of holding, which is an important fact to be known in computing the available water supply along our plains rivers, the beds of which, as a rule, have a sand and gravel formation. Since coarse gravel will yield up about 80 per cent. of the water absorbed, fine sand will give up considerable less water than coarse gravel, possibly not more than about 60 per cent. of the amount of water so absorbed. While these results are not given as being absolutely correct, yet they are given in connection with the water absorption tests, in order that some basis for the calculation of the quantity of water contained in any given stratum of sand or gravel, the dimensions or coarseness of which are known.

CARE OF WINDMILLS.

There is no piece of mechanism in existence to-day from which so much is expected and hoped for that receives less care and attention than a windmill. Once in position and started into motion it is regarded more as a sort of weather vane or perpetual-motion machine than a windmill. They, however, are not unlike other mechanical devices that are liable to get out of order and occasionally break, and when they do break, nine times out of ten it is on account of the lack of attention, which the owner did not deem necessary to bestow; after which a critical inspection is made, not so much for the purpose of finding out the true cause of its failure to work as it is to find fault with construction.

A windmill is a delicate piece of machinery, especially designed and constructed to do duty in all kinds of weather and to supply a cheap and lasting power for mankind; a machine that must work constantly and continuously; one that will run in sunshine and in rain, by day or by night, in summer time and winter time; in fact, it is expected to run whenever the wind blows sufficiently strong to move it, from a gentle breeze to a hurricane; even expected to regulate and adjust itself to every wind that blows, come from whatever quarter it may; it is expected to be on duty and do duty, simply from the fact that it is a windmill. Such a machine does require attention; a constant care and watchfulness must be given it or it is liable to go wrong. The least thing about it, if displaced, is liable to throw it out of balance, and if continued in motion may prove its destruction.

Regular oiling, critical inspection of bolts and nuts, stay rods or braces tightened up, broken ones replaced, guard against friction in boxes, journals or plunger rod; look well to your water supply, and see to it that it is ample for size of pump employed. An inadequate water supply causes more breaks in pumps and windmills than all other causes combined. So look well to a sufficient water supply before a mill and pump are put in motion. Great care

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should be exercised to see that a windmill is not overloaded, but so regulated as to move its load placed upon it in the least wind that is desired to run it, which will then increase in efficiency as the wind grows stronger. A perfect equalization of power as between windmill and pump must be had to get best results. Power of wheel in a given wind must be ascertained, as also capacity of pump and weight of load which it is to move. (See tables in this report.)

DUTY OF WATER.

There is no fixed rule as to the duty of water; much depends upon the kind, quality and texture of soil to which it is to be applied, as well as the kind of crop that is to be produced. The duty of water varies fully as much in the kind of crop raised as it does on the kind of soil to which it is applied. A coarse, open or porous soil will absorb water very readily, while at the same time it will pass away by percolation, evaporation and through plant growth with equal rapidity. A finely-grained or well-pulverized soil will not take up water as fast as a coarser soil, but it is capable of absorbing more water and retaining it longer than a coarser soil, lessening the per cent. of evaporation as also of percolation and maintaining a more compact fountain for plant growth to draw from. Deep plowing and thoroughly pulverizing the soil puts the land into the best possible condition for the absorption and retention of water. Shallow and repeated cultivation is the best system against loss of water by evaporation. When the supply is abundant there is greater fear of using too much rather than not enough; especially is this so with beginners in the artificial application of water to growing crops. As a rule it is much safer to use too little water, to begin with, than too much, since less damage is likely to occur; while an insufficient amount of water means a short or partial crop, an over supply or too much water in many instances destroys the crop. The safest plan is to apply water oftener and not so much at any one time, rather than flood a field with twice the amount of water the soil can hold and readily absorb. Too much water makes land foul and miry, which is liable to destroy plant growth.

HOW TO CONSTRUCT A RESERVOIR.

To construct a reservoir large enough for a six-inch pump, measure off a plot of ground 75 by 125 feet, longest east and west; take 1½ feet of soil from the inside of said plot with which to form the embankments, which will give sufficient to make them four feet in height on outside and 5½ feet on inside, base of embankments 12 feet wide and top about 2 to 2½ feet wide; this done, plow up about three inches of additional soil on inside of reservoir and harrow same until soil is thoroughly pulverized. Then turn your pump or pumps on and thoroughly saturate with water the fine soil or bottom of reservoir as deep as it was plowed, after which turn your pumps off and let it stand until it is dry enough so by admitting a horse or horses they would not mire, or, in fact, penetrate the soil with their hoofs any deeper than the last plowing, continuing the tramping process until horses' feet will make no impression on the soil so packed. This will insure a good, solid bed, through

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which water cannot escape by percolation. The inside and outside of the reservoir ought to be sodded, especially the inside embankment, with a stiff gumbo sod, which will hold the loose earth in place and keep the water from washing out the embankments, which embankments ought to have a slope of say 45 degrees, and sodded to the top. Good boxes or gates ought to be made and put in position before embankment is made, and ought to be on a level with ground surrounding outside of reservoir or land to be irrigated, which boxes ought to be thoroughly packed with soil underneath boxes, as also on sides and over the top, so as to prevent the water from cutting through the embankment at any point surrounding the box. Too much care cannot be given this part of the work. When a bed of sand is encountered at bottom of reservoir, several inches of black loam or clay must be spread over the bottom before water is admitted or the packing process is begun. This system closely followed will insure you a good reservoir and the saving of much water by leakage or percolation, and insures you an abundance of water for fish culture, ice harvest, as well as for irrigating purposes whenever you raise the water in your pond to the height of the discharge point, below which you will always have 18 inches of water, as you cannot rob yourself or your fish in the pond, or let it dry up so as to necessitate repuddling or re-tramping.

The foregoing method has been generally followed in the Arkansas valley, which, however, has proved faulty in other portions of the state, especially on the higher lands, where it became necessary to puddle the embankments and underneath them, as well as the interior of the reservoir. See, also, specifications in another part of this report.

SUBSURFACE IRRIGATION BY TILE SYSTEM.

For economy in the use of water for irrigation, where but a limited amount of acres are employed, the tile system is by far the best. But to do this so as to give best results from the least amount of water applied, it must be properly and systematically done.

The old system of digging deep trenches—20 to 30 inches in depth—has been totally discarded. The best results recorded are from tile that are laid from 16 to 18 inches below the surface of the ground, the soil being first thoroughly broken up and pulverized as deep as the tile is laid, which enables the water to penetrate the earth laterally from four to six feet on either side of the tiling, giving it a more even and regular water supply. Where the tile is deeper much more water will be required, and unless the soil was similarly prepared as when laid shallower it would not reach out one-fourth the distance, and for all practical purposes such a system would be utterly useless. Tile should be laid practically on a level, if land permits, to get best results. Avoid the tiling system in orchards or for deep-rooted crops, since deep rooted plants, vines, and trees, with their small fibrous roots will soon reach down and out to the depth of the tile, and enter it, which will soon fill up, stop the flow of water and burst the tile, causing crops to perish beyond the point of break or stoppage for lack of water supply, and the difficulty cannot be detected until the crop shows signs of lack of water supply. To get best results from such a system the pipe or tiling ought to be not to exceed 12 feet apart.

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DISTRIBUTION OF WATER.

In order that the best possible results may be realized from the artificial application of water to land, much depends on the equal distribution of the water over the land to which it is applied. This cannot be successfully done when the land is in a rough and uneven condition. Neither will it produce the results hoped for; besides it is a great waste of water. Drowning out a crop on the lowland on account of too much water while the crop will perish on the higher ground for the want of it. A perfectly even application of water must be had to all parts of the field irrigated, to insure success. This can be done by leveling the land so as to have a gentle slope away from the ditch or laterals supplying the water. Reservoirs ought to be placed on the highest point of the land from and to which it is to supply water. Ditches conveying water from reservoir to land ought to be so constructed as to hold the water above highest level of land to which it is carried, thus enabling the irrigator to handle the water with perfect ease and under absolute control, to all portions of his field or garden.

FALL OR WINTER IRRIGATION.

One of the most important factors in the artificial application of water to land is to know when to do it, and how it may be best applied to insure the best results from a limited water supply. The thorough saturation of the soil during the fall and winter has fully demonstrated the fact that a cereal or forage crop will require from one-third to one-half less water to mature a full and bountiful harvest than the plan of spring and summer irrigation with an abundance of water. The soil appears to demand something more than the mere plowing and watering. It seems to need the freezing and thawing process during the winter and early spring, which it cannot get or have unless the soil is thoroughly soaked with water during the fall and winter. To begin with, all lands under irrigation, before any water is applied to them, ought to be subsoiled 18 or 20 inches in depth; when that is done, it should be thoroughly saturated with water and, as soon as dry enough to plow, to be plowed and fully prepared for seeding. No crop ought to be put on any ground, no matter at what season of the year it is put in or planted, until this preparation has been made—whether for wheat in the fall, or corn, oats or barley in the spring; vegetable crops, as well. This system insures an early appearance of the plant, soon after seeding or planting, and just when one expects to see it come up. The secret of deep plowing or subsoiling and thorough irrigation after land is so prepared is, that the water is placed far below the root of the plant, instead of being above it, increasing the condition of plant growth, rather than lessening it; besides, water is not so readily evaporated when deposited deep, and held back much longer, until drawn upon to sustain plant life, rather than to be drawn from a shallow bed by the rays of a noon-day sun. Then, again, by fall or winter irrigation a much larger area can be covered and water is easier distributed, the loss of water by evaporation and percolation is much less, and when the supply of water is limited, this is a very great advantage, especially with the individual pumping system, by wind power. Windmills will run in winter time just as well as in summer, and there is no valid reason why they

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should not; keeping them in constant operation will give an increase of water, which means an increase of acres to be irrigated. An acre irrigated during the winter means just that much less water to that irrigated acre during the summer to follow. Winter irrigation means an increased acreage from a limited water supply.

FACTS WORTH REMEMBERING.

An acre foot of water is 325,851 gallons.
An acre of ground contains 43,560 square feet.
One cubic foot per second: 50 California inches.
One cubic foot per second: 38 Colorado inches.
One cubic foot per second, one day: 2 acre feet.
One cubic foot per second, one year: 724 acre feet.
A cubic foot of water weighs about 62½ pounds.
A cubic foot of water contains about 7½ gallons.
A gallon of water weighs about 8⅓ pounds.
A gallon contains 231 cubic inches.

An acre of ground, covered with 12 inches of water is called an acre foot or 43,560 cubic feet, or 325,851 gallons of water.

A second foot of water is the quantity represented by a stream 1 foot wide and 1 foot deep flowing at the velocity of 1 foot per second.

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Small Pumping Plants on the Uplands.

By M. B. TOMBLIN.

The following extracts from letters and reports, giving information and opinions as to the success of the small pumping plants for irrigation purposes on the uplands, will prove interesting:

E. Doom, Jennings, Decatur county.—Irrigating one-half acre with windmill, from a well 100 feet deep, cultivating a crop which he valued at $200; states in his letter, "I believe that one man can, with a 10-foot windmill, pump enough water from a 100-foot well to water a garden that will raise all of the vegetables and potatoes to do a family of seven for a year."

Mr. G. F. Kreger, Oakley, Thomas county.—Pumping water from a well 82 feet deep, with a 10-foot mill, irrigating one acre, estimates the value of product raised from the acre at $150.

Mr. T. T. Dean, of Cedarville, Smith county.—During the year irrigated one-half acre from a well 40 feet deep; in his letter he states, "My onions yielded at the rate of 600 bushels per acre, potatoes 500 to 600 bushels, corn 60 to 70 bushels. Every man should irrigate at least one acre, as he is then always sure of a cellar full of truck, which goes a long ways towards living. I have not been to $5 cost on my plant in three years, since starting the same. I have a steel wheel geared, as they pump in less wind. I hauled clay from a railroad cut to line my reservoirs, as the soil was loose sand."

S. N. Norris, Sylvan Grove, Lincoln county.—Irrigated from a well 73 feet deep, and the product from his one-half acre he valued at $125. He says, "I think irrigation by pumping quite a success, but do not think that it will pay to pump water that deep (73 feet) for a field crop."

M. L. Walcher, Greensburg, Kiowa county, irrigated from a well 70 feet deep, and says, "From two to four acres might be irrigated with a windmill to raise an abundance of vegetables. Plenty of water can be raised for garden and orchard and 400 or 500 head of cattle by one pump."

Daniel J. Rundell, Almena, Norton county, has during the past year irrigated three acres from a well 93 feet deep. His letter is as follows: "I think that irrigation by a windmill and pump is a success to the extent of irrigating a garden and truck patch for family use, but to attempt to lift water 100 feet to irrigate ordinary farm crops I would consider to be a failure."

Richard England, Monument, Logan county, has irrigated this last year about one-fourth of an acre from a well 100 feet deep; the value that he placed on his crop was $100, and says, "I have just constructed a reservoir 110 feet in diameter, and have five feet of water in it at this time. I use a 10-foot Dandy steel mill, with a 4-inch cylinder and 2-inch pipe, and I raise the water just 100 feet. I have irrigated all of the winter, and it keeps my reservoir nearly full all of the time. I intend to build another reservoir this spring."

J. R. Crothers, Liberal, Kas., irrigating a garden of 35 square rods, the crop value of which was $100, says, "I am an invalid and have had to hire nearly all of the work done. I have raised nearly all kinds of garden truck, including potatoes, and it was the finest I have ever seen grow anywhere."

D. E. Barnes, Hays, Ellis county, irrigated a small garden, and says, "I bought a second-hand windmill and repaired it myself. The outlay was so

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small and the return so great that I am an enthusiast on the subject, if it is conducted on a small scale."

E. Nelson, McGraw, Sheridan county, irrigated one-eighth of an acre. Says, "On a space 10x26 feet I raised 10½ bushels of tomatoes; on a space 11x40 feet I raised 105 heads of cabbage that averaged seven pounds, and other truck in like proportion. When my neighbors saw me planting my garden they said that I would never get anything where I had it so thick, but when they made me their annual visit this fall, they said that I was a 'world-beater' on the garden. I plant my squash inside the fence, training the vines through the fence, thereby protecting the plant while it is little, and I raised wagon loads of squashes; I do likewise with cucumbers on the opposite side."

John Ulch, Barnard, Lincoln county, has irrigated two acres of ground, and the estimated value of his crop was $600. Regarding his plant, he says, "It is at the A. T. & S. F. R. R. water tank, and I use water from the tank to irrigate with."

John Schlyer, member of the legislature 1895, Hays City, Ellis county, has irrigated one acre of ground from a well 25 feet deep. His value of crop raised was $250. He says, "Irrigation by pumping, in my opinion, will pay very well for vegetables—potatoes, cabbage, etc. I have had no experience with field crops."

August Hahn, Stafford county, Ellinwood post-office, has irrigated five acres, elevating the water by horse power from a well 20 feet deep, and figures the value of his crop at $1,200. In his letter he says, "Beginners should go slow; generally they will apply too much water, and do not do enough cultivating; furthermore, heavy land (gumbo) is not fit for irrigating, a loamy, sandy soil being much the best."

Geo. Gripton, Smith Centre, Smith county, has irrigated about five acres, and uses a jumbo windmill. He states, "The value of my crop raised, I consider was $500. Irrigation by pumping is a success for vegetables, but not for field crops."

S. A. Marteeny, St. John, Stafford county, is irrigating three acres from a 40-foot well, and has raised potatoes, strawberries, blackberries, raspberries and garden truck to the value of $300 per acre. He says, "I have been irrigating garden and small fruits in a small way for the past 10 years, and I have found that it pays largely."

R. B. Huddle, Selden, Decatur county, is irrigating one-sixth of an acre from a 40-foot well, using a 10-foot windmill, and estimates his crop at $100, and says, "I raised tomatoes at the rate of 300 bushels per acre, peas 100 bushels, beans 100 bushels, radishes 600 bushels, and cucumbers at the rate of 200 bushels per acre. I am going to put in a larger plant next year if I can afford it, as it will pay big."

J. C. Haffeditz, Hoxie, Sheridan county, during the year 1896 irrigated one acre of land from a well 128 feet deep, using a Halladay 14-foot mill, and was very successful in raising strawberries, grapes, trees and garden truck. He states, "I have nine square rods of strawberries, from which we have gathered 1,200 quarts of berries. I am of the opinion that irrigation by pumping on the uplands would be a success to about the extent of five acres out of 160, with proper machinery. The trouble is to get the well deep enough into the sand, but I believe that it could be done with proper machinery. I believe that the sugar beet should be thoroughly tested in a number of places in western Kansas and Colorado and ascertain the amount of sugar that might be produced. I believe that this will yet be the home of the sugar-beet industry."

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Ben. C. Rich, Ellis, Ellis county, says, "My water supply is drawn from a well 45 feet deep and about 40 feet lift, when the pump is in operation; pump, 2-inch supply and discharge pipe, cylinder 4x16, power 8½-foot steel mill on 9-inch stroke; two reservoirs of 200 and 400 barrel capacity, stocked with German carp. I irrigate from three to six acres of orchard trees and garden, according to season. The orchard and garden is worth at least $200 a year to my family by means of supplies of vegetables and fruit; we also sell considerable of the surplus. I have been irrigating since July, 1891. Irrigation of two acres or more means a good supply of living necessities to any family which practices it.

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Irrigation Statistics.

By WM. B. SUTTON.

One of the things which every member of the Board deemed essential to the presentation of the subject of irrigation to the legislature was the obtaining and tabulating of information relating to the condition and progress of irrigation in the state.

Have the people in Kansas attempted irrigation? If so, have the results been satisfactory? Has it paid or given promise of reward for the efforts and expenditures? Has the practice of irrigation in Kansas grown? Is irrigation practiced among the tillers of the soil or is this industry confined to the floors of irrigation conventions and the column in the weekly newspaper headed "Irrigation"? What return does the irrigator receive from his lands and what is the verdict of the man who actually tills the soil and "waters the land with his foot"? How and where does he get his water? Is there benefit in it to the state, or is it a fraud or a fad?

To obtain light on these subjects, a series of questions was framed and a supply of blanks sent to every township trustee in the territory west of the 98th meridian, requesting him to procure a blank to be filled out by every irrigator in his township.

The Board also ascertained as far as possible the names and post-office address of every person within the territory who was supposed to be practicing irrigation and sent to him a blank with a stamped envelope for its return, and requesting a full report.

A copy of the blank sent out in the spring of 1895 is here given.

County ....., township ....., name ....., post-office ... . How many acres do you irrigate? .....; when did you first begin irrigation? .....; what is your source of water supply—stream, well or storm-water reservoir? .....; depth and diameter of well? .....; depth to water? .....; thickness of water-bearing stratum? .....; how much is your water supply? .....; amount pumped daily during growing season? . ....; what power do you use? .....; kind of pump? .....; size of cylinder? .....; length of stroke? .....; cost of power per week? .....; give cost of plant complete, not counting your labor .....; what crops did you grow in 1894?.....; give yield of each per acre .....; give gross value of your irrigated crops in 1894 .....; how often did you apply water to various crops? .....; is irrigation by pumping a success? .....; how much will you irrigate this year? .....; give name and address of your neighbors who will irrigate this year for the first time .....

The information contained in the reports returned satisfied the Board that the same thing should be done again in the spring of 1896, and it accordingly was.

The tabulations of the main facts shown by the reports for the two years are here given separately.

These tabulations are made from the reports sent in by the individual irrigator himself and usually over his own signature, and are in the nature of direct and positive testimony. An exception to this is the number "Beginning Irrigation in 1895"—1,241, as appears in the table of 1894.

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This is in the nature of hearsay. A report of the operations of 1895 was not asked in the blank, but the irrigator was asked to send in the names of those who would begin to irrigate in 1895. One thousand two hundred and forty-one is the number thus reported as beginning in 1895. The 1895 column of the table of 1895 statistics shows reports from 669 as beginning their irrigation operations in 1895. The number reported in the table of 1895 as beginning their operations in 1896, which is of the nature of hearsay above alluded to, is 1,410.

If the same percentage held good for 1896, as appears to have in 1895, the real number beginning irrigation in 1896 would be 761, which is probably very close to the fact.

A study of these tables will better than any other way acquaint the inquirer with the rise and growth of irrigation in Kansas.

The earliest irrigator reported is Joe McAdams, of Northfield, Sherman county, who reports his operations as beginning in 1875, and next to follow him is L. A. Martin, of Lakin, Kearny county, in 1878, and next is Geo. Allaman, of Wallace county, in 1879.

Little progress seems to have been made, according to these reports, until 1887, when 17 new entries were made in the list. The number annually increases from 1887 until 1893, when 106 new plants were established; 250 in 1894, and 669 in 1895; 1896 has probably witnessed the establishment of not less than 1,000 new plants.

It will be noted here that the giving of this information was entirely voluntary on the part of the irrigator, and that it did not suit the convenience and inclination of every person to make us a report.

We heartily recommend that the subject be followed up by the legislature and that the secretary of agriculture be directed to gather in the future like statistics and such others as may be essential to a full knowledge of irrigation in the state.

A table has also been made of the depth of wells from which water for irrigation purposes is pumped, which is here given.

DEPTH OF WELLS.

Number of wells less than 10 feet	16
Number of wells 10 to 20 feet	96
Number of wells 20 to 30 feet	54
Number of wells 30 to 40 feet	63
Number of wells 40 to 50 feet	22
Number of wells 50 to 60 feet	20
Number of wells 60 to 70 feet	14
Number of wells 70 to 80 feet	34
Number of wells 80 to 90 feet	21
Number of wells 90 to 100 feet	31
Number of wells 100 to 110 feet	12
Number of wells 110 to 120 feet	14
Number of wells 120 to 130 feet	21
Number of wells 130 to 140 feet	8
Number of wells 140 to 150 feet	16
Number of wells 150 to 160 feet	12
Number of wells 160 to 170 feet	5
Number of wells 170 to 180 feet	12
Number of wells 180 to 190 feet	5
Number of wells 190 to 200 feet	4
Number of wells 200 to 220 feet	1
Number of wells 220 to 240 feet	2

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IRRIGATION STATISTICS FOR 1894.

County.	Is irrigation by pumping a success? No.	Is irrigation by pumping a success? Yes	Total money cost of windmill plants	Total money cost of horse-power plants	Total money cost of gasoline plants	Total money cost of steam plants	Power not given	No. using wind and giving cost	No. using horse power and giving cost	No. using gasoline and giving cost	No. using steam and giving cost	Source not given	No. using storm reservoirs	No. using wells	No. using stream	No. of acres reported in 1894	No. of acres reported in 1895	No. making report of 1894	Began Irrigating: No date	1895	1894	1893	1892	1891	1890	1889	1888	1887	1886	1885	1880	1879	1878
Barber		1					9	9				3		6	6	63 00	85 00	9		1	3	2	1		1			1					
Barton		9	$2,606	$51		$800	1	6	1		2			12	1	33 10	101 00	13		3	7			1			1						
Cheyenne		4	1,170				6	6				1		6		129 00	457 00	15		3	3	2	1			1							
Clark		7	480				3	5						3		1 25	16 75	8		2	5	2											
Comanche		3	102				3	3						3	1	3 00	474 50	3			1												
Decatur		20	1,100				20	12						7	23	209 80	18 00	32		2	12	3	1										
Edwards		11	985				20	6				1		13		5 00	69 00	14		3	8	2											
Ellis		7	640	100		$300	8	7	1	1				9	3	7 50	11 00	12		6	4	2											
Ellsworth		5	555				3	6				1		11		3 00	168 00	12		5	1	1											
Finney		6	500				6	2						4	1	155 00	227 50	5		1	3	1											
Ford		4	360				3	3						7	2	176 00	15 50	9		1	5	1	2										
Greeley		7	5				5	5		1				14		7 75	22 75	14		2	5	2	2										
Gove		12	1,540				1	13				1		9		10 75	160 75	10			4	2											
Graham		9	1,040				1	9						11	10	111 00	18 50	21		2	7	2											
Grant		6	375				17	4				1		14		2 50	463 75	14		2	8	2											
Gray		10	872					14						19	3	165 00	540 00	22	2	9	2												
Hamilton		12	1,510					12	1					2	7	530 50	9 00	5		2	4	1	1										
Harper		1	40					1						5		90	2 25	4			3												
Haskell		3	335					3					1	3		25	26 50	7			5	1											
Hodgeman		2	100					1				2		4		11 00	32 25	8			5	1											
Jewell		2	345					2					1	6	1	75	2,719 00	44		2	5	3	1										
Kearny		1	100					1					1	6	1	2,521 00	472 00	17		1	5	2	1	4				1					
Kingman		21	1,554				33	11			1		1	10	3	16 00	32 00	6			1	1	1	1									
Kiowa		3	465			500	12	4				1		1	1	27 00	11 00	6			4	1											
Lane		2					6							5	1	50	61 00	18		2	8	3	1		1								
Lincoln		8	330	75		300	2	4	1	1		2	1	10	5	77 00	158 00	22		2	8	3	2		1								
Logan		7	502	40			10	15	1			2		17	5	66 00	309 75	17			8	1	1		1								
Meade		18	1,895				6	3						12	5	45 50	14 00	5			4												
Mitchell		2	710				14	14						2	2	5 00	1 87	9			13	4											
Morton		1	150				3	4				2		7	1	12	9 25	19		2	4	1											
Ness			585				3	3						16	1		35 75	26			6	4											
Norton			1,666				3	6						10	6		98 00	14			5	1											
Osborne		1	1,350	200				1						19	2	14 00	440 00	26			11	4											
Pawnee		2	3,121	140	500			2		1			2	23		45 50	48 00	29			21	7	1										
Phillips			1,461				1	1						11		02 00	02 00	11			6	2	1										
Pratt		2	1,225				1	6				1		8	5	5 00	300 00	14			7	3			1								
		6	650				4	4						9		21 00	11 90	8			1	1											

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IRRIGATION STATISTICS FOR 1895.

County	Is irrigation by pumping a success? No.	Is irrigation by pumping a success? Yes	Total money cost of windmill plants	Total money cost of horse-power plants	Total money cost of gasoline plants	Total money cost of steam plants	Power not given	No. using wind and giving cost	No. using horse-power and giving cost	No. using gasoline and giving cost	No. using steam and giving cost	Source not given	No. using storm reservoirs	No. using wells	No. using stream	No. of acres reported in 1895	No. of acres irrigated in 1895	No. making report of 1895	Began irrigating: No date	1896	1895	1894	1893	1892	1891	1890	1889	1888	1887	1886	1885	1884	1883	1882	1881	1880	1879	1875
Barber		3	$1,000				17	4				7		3	11	102.25	236.50	21		4	7	6	1	1			1									1	
Barton	1	21	2,696			$150	4	20			1			24	1	53.72	67.42	25	1	1	18	5	1	1			1										
Cheyenne		9	1,135				15	9				2		9	25	529.25	781.00	24		1	14	4	1	2													
Clark		11	1,629				5	6				2		13	6	15.87	338.00	21		2	6	1	2			1					1						
Comanche		5	493				1	5						6		6.30	126.5	6			1	4															
Decatur		17	750				10	11				2		19	9	123.76	123.41	30			6	13	3	1													
Edwards		28	2,972			55	5	25			1	2		29		51.57	661.50	31			5	17	2	1													
Ellis		12	1,171		$425		2	9	3			2	1	4	4	41.75	41.75	14			2	5	2	1													
Ellsworth		12	1,420				3	11				1		13		10.16	18.95	14			1	2	2	1													
Finney		24	2,820				21	18				1	1	33	23	2,114.33	1,561.25	39			1	9	2	2													
Ford		29	3,270			400	4	30						33	14	153.75	159.75	35			2	5	2	2													
Greeley		10	2,071				1	19				1		20	2	21.58	53.25	20			1	6	1	2													
Gove		23	1,446				7	20				1		23	1	29.79	50.91	27			1	14	2	1													
Graham		12	1,011				13	11				1	2	15	7	135.00	232.00	24			2	9	5	1													
Grant		25	2,038		50		2	21				2	1	25	2	46.18	89.35	27			4	17	4	1													
Gray		24	2,924				2	26	1			3		26	17	451.41	841.25	46			5	18	3	1													
Hamilton		17	1,635				20	26				2		11	18	525.50	909.75	31			2	4	2	1													
Harper		1	625				20	2						1	1	1.50		2				1															
Haskell		7	2,545				3	16				2		1		9.75		23			1	1	1														
Hodgeman		15	1,463				3	15				3		15	21	23.25	14.50	18			1	4	2	1													
Jewell		3	1,071		15		3	7		1		1	1	8		14.37	47.50	11			2	2	2	1													
Kearny		3	1,203		75		23	9		1				7	1	1.25	41.25	33			2	6	1	1													
Kingman		1	1,394			400	7	15			1	1		15		658.87	1,929.50	23			2	4	1	2													
Kiowa		5	380				5	3						4		73.50	121.50	8			1	4	2	1													
Lane		5	1,775				5	18						20	4	48.76	146.28	23			2	4	1	2													
Lincoln		21	1,394		100		5	12		1	1			14	3	53.12	63.27	23			1	12	2	1													
Logan		19	1,320		115	400	6	35	1		1	3	1	39	5	39.07	74.87	20			2	10	3	1													
Meade		40	4,220			$300	6	18	2			4		35	2	50.40	99.70	46			3	10	6	2													
Mitchell		20	2,075				30	18				2		35	2	412.92	656.37	46			1	5	2	1													
Morton		4	435				3	3				2		2	2		6.50	6			1	1															
Ne-s		3	1,434				5	12				2		14	3	46.47	54.25	17			3	2	1	1													
Norton		9	2,022		100		6	5			1	1		30	2	36.76	46.79	33			2	11	4	1													
Osborne		26	2,260				7	18				5		19	3	149.87	139.00	27			1	12	5	1													
Pawnee		10	2,167		132	600	5	16		1			3	21	3	37.25	71.50	27			2	10	6	1													
Phillips		1	1,148			300	3	26			1		2	27	2	136.75	197.25	30			3	6	2	1													
Pratt		1	1,009				4	7				1	1	7	1	23.50	81.00	11			1	4	1	1													
		1	557				11	6						12	5	43.35	238.47	17			1	1															

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These reports also show as follows:

	1894.	1895.
Gross money value of crops, per acre, all tracts	$14 75	$20 08
Gross money value of crops, per acre, tracts over 10 acres	21 05	11 15
Gross money value of crops per acre, tracts 10 acres and under	74 64	57 15
Number of acres irrigated	5,166.67	8,530.63
Average money cost of windmill plants	$118 89	$116 97
Average money cost of steam plants	372 50	260 00
Average money cost of gasoline plants	500 00	550 00
Average money cost of horse-power plants	85 10	78 43

To ascertain the opinions of those actually engaged in pumping water for irrigation purposes, this question was propounded in the blanks furnished for both years: "Is irrigation by pumping a success?"

	1894.	1895
Affirmative answers	440	970
Negative answers	4	36

When any other business can make a showing equal to this it will be time to call the irrigator a crank and class his occupation among the lost arts.

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Report of Inquiries on Irrigation in Europe.

It will be very interesting to read in connection with the foregoing statistics a report of inquiries into irrigation in Europe made by President Fairchild, of the State Agricultural College, an advisory member of this Board, during a trip abroad in 1895. Interesting comparisons may be made between the showings of the two reports. President Fairchild's report is as follows:

To the State Board of Irrigation:

Gentlemen—Upon my undertaking, June, 1895, for personal pleasure and general information, a two months' tour in England, Scotland, France, Switzerland, Germany, and Holland, you were pleased to gain for me, from the governor of the state, a commission to inquire into any matter touching irrigation which might fall in my way. The circumstances of my journey were such as to prevent any extensive observations upon the actual practice of irrigation, as I could not visit the most noted enterprises of the south of France. These, I was willing to pass by for the reason that, being government enterprises, they have been thoroughly described in most excellent government reports, which have been well set forth by experts from this country like Prof. C. A. Kenneston, of Salt Lake City, Utah, and Prof. L. G. Carpenter, of Fort Collins, Colo. It was improbable that my observations or inquiries should add anything to what these gentlemen have already presented.

The few systems of irrigation passing under my own observation were confined to pastures and meadows along the upper and middle Rhine, where the ordinary methods of conveying water in ditches from which it is spread over levels and slopes is universal. I could discover no new or superior contrivances in these old and long-established irrigations.

My inquiries were limited to three classes of questions most important in Kansas experiments with irrigation at this stage of our progress: First, the general feasibility of raising water from wells for a profitable irrigation; second, the decisions from actual experience as to how little water may be made to serve for irrigation of a given area under given crops; third, some data for estimating the general average profit from irrigated lands.

With these questions in view, I visited the chief of hydrographic agriculture for the republic of France, at his office in Paris. A most cordial reception was given me, and a special interview was accorded me, at which I made my questions understood, though with some difficulty for want of fluency in a foreign tongue, while the chief and his clerks were no better equipped than I.

My questions, however, were fairly presented and as fairly answered, while I was given every opportunity to examine the extensive plans for future enlargement of the irrigated lands in the region at the foot of the Pyrenees.

To the question as to irrigation by wells, the answer was distinct, that no information was at hand, or anywhere to be secured, a few individuals only

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having made the attempt on a small scale. No thought had been given to the possibility, and no interest had been aroused. To the question as to minimum amount of water, I found no answer, for the investigations of the department had not yet required its settlement. To the third question, upon actual profit, an encouraging answer was given at the time with the promise of definite data in future. Especially interesting was a final interview with M. Emile Briotet, engineer in hydraulic agriculture, and I left him with admiration for his intelligent interest in all that pertains to experimental irrigation.

Since my return to college duties, I have received from M. Briotet a statement prepared for the French Association for the Advancement of Sciences in 1887 by M. Fontes, engineer for Toulouse, which is so interesting and explicit that I translate portions of it for this report, transcribing his tables with slight condensation and adaptation to our land measurements and our money. In doing this I have treated the French hectare as 2½ acres, and the franc as 20 cents. Though this treatment is not strictly accurate, it does not mislead in estimating results.

The pamphlet is entitled: "Considerations upon the Advantages of Irrigating Canals, by M. Fontes, Engineer in Chief at Toulouse. September, 1887."

The author, after saying that he presents simply a study upon the utility of irrigation, and that technical works on irrigation, when questioned as to the interest which proprietors have in irrigating their lands, do not in general answer the needs of those who consult them, proceeds as follows:

"This side of the question is above all the most, not to say the only, interesting one for irrigators."

"Irrigation enters into the category of industrial culture. Before undertaking it, one ought to ask himself,

"1. To what expense for first establishment shall I be put in order to place my lands under irrigation?"

"2. What increase of net revenue shall I receive from it?"

"Such are the questions which propose themselves to the proprietor and, let us say too, to all those who have either to give advice upon establishing irrigation ditches, or to share in any manner whatever in an enterprise of this kind."

"Now this question, which we have up to this time found answered only by the statement of predictions not sanctioned by a sufficient number of results observed, and only by examples which it will not always be prudent to follow, is not even stated in most didactic treatises for want of results of experience in sufficiently large quantity. It is this gap which we wish to attempt to fill in what concerns the region placed under our oversight.

"To this end we have collected with care the practical results of irrigation of various classes, extended over an area of about 3,000 acres taken in different parts of the department of the High Garonne.

"We say, intentionally, irrigations of various classes, for our statistics apply to irrigations which, though but little separated geographically, are practically in regions quite distinct in the various points of view topographical, geographical, and meteorological."

After describing the region irrigated as subject to two periods of drought annually, well meriting the name of "country of thirst," the author gives the particulars as to irrigating canals along which lie the plots of land irrigated, and then condenses into interesting tables the statistics gathered. He says:

"We have, unhappily, been unable to collect data from the entire surface

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Number	Acres in plot	Nature of soil	Nature of subsoil	Kind of crop	Mode of irrigation	Date of first irrigation	Total annual increase resulting from irrigation	Annual increase from irrigation, less 10 per cent. to restore capital	Cost of preparation, per acre, of entire plant	Annual net income before irrigation, per acre	Average annual cost of tillage, etc., per acre	Annual net income after irrigation, per acre	Actual increase, per acre, from irrigation, less 10 per cent. for restoring capital
First group; proprietors showing best returns in money.													
1..	20+	G.	G.	Sf.	T.	1881	$556 60	$516 20	$20 00	$8 40	$10 40	$36 00	$25 60
2..	5	G.	G.	M.	Sl.	1885	132 00	25 50	213 20	12 00	16 00	38 40	5 04
3..	70	G.	G.	Sf.	Sl.	1879	1,668 00	1,515 00	20 40	10 40	9 44	32 64	20 16
4..	4.6—	S.	G.	M.	Sl.	1879	96 20	91 60	10 00	18 40	18 08	39 36	19 92
5.	8.1+	G.	G.	Sf.	Sl.	1880	169 00	138 60	30 80	9 60	9 60	30 40	17 28
6..	1—	G.	G.	Sf.	Sl.	1878	18 40	16 20	23 04	36 00	15 52	35 84	17 52
7..	3—	P.	G.	Sf.	Sl.	1879	52 40	46 40	20 80	10 40	7 20	28 80	16 32
8	3+	Cl.	St.	M.	Sl.	1877	57 00	54 20	8 80	12 80	8 40	30 80	9 20
Second group; proprietors showing least return in money.													
1..	70	G.	G.	M.	Sl.	1879	$354 00	$315 00	$5 20	$6 08	$7 20	$10 80	$4 16
2..	5	P.	St.	M.	T.	1878	34 00	25 60	16 80	3 20	6 80	10 00	5 68
3..	2+	P.	G.	M.	Sl.	1879	16 60	9 20	34 40	12 00	7 60	19 80	4 16
4..	15—	P.	G.	M.	Sl.	1879	112 00	67 20	30 40	12 00	7 60	19 80	4 56
5..	6—	G.	G.	M.	Sl.	1880	47 60	35 80	20 00	8 40	8 80	16 40	6 00
Third group; unusually large areas.													
1..	70	No. 3 of first group.				.....	$1,668 00	$1,515 00	$20 40	$10 40	$9 44	$32 64	$20 16
2..	51	V.	V.	M.	Sl.	1879	765 80	636 00	25 40	17 76	8 88	32 80	13 28
3..	65	Cl.	St.	Sf. & M.	Sl.	1879	810 60	587 80	34 24	11 60	10 48	24 08	9 04
4..	142	Cl.	G.	L.	Ter.	'80-'82	1,762 00	990 00	54 40	1 60	7 04	14 00	6 96
5..	111	V.	G.	M.	Ter.	1880	1,246 40	792 40	40 80	8 80	8 80	20 00	7 12
6..	66	G.	G.	M.	Sl.	'75-'81	664 00	521 80	21 44	7 28	6 40	17 44	8 00
7..	81	P. & Cl.	St.	M.	Sl.	1879	796 80	545 00	32 00	4 80	7 44	14 64	6 64
8.	70	No. 1 of second group.				1879	354 00	313 00	5 20	6 08	7 20	10 80	4 16
Totals and averages.													
...	666	.....	.....	.....	.....	.....	$8,067 60	$5,903 60	$32 40	$7 44	$8 24	$19 60	$8 88
A community reporting poor results from irrigation.													
...	92	.....	.....	.....	.....	'77-'81	$904 20	$578 60	$35 20	$5 12	$6 56	$14 88	$6 24
General average of all results gathered.													
...	1,446	.....	.....	.....	.....	'77-'81	$16,955 20	$12,811 60	$28 64	$9 52	$8 64	$21 20	$8 80

ABBREVIATIONS: G. = ground. Cl. = clay. S. = sand. P. = pebbly. St. = stone. T. = terraced. Sl. = sloped. M. = meadow. Sf. = sainfoir, a forage crop. L. = Lucerne, or alfalfa.

irrigated, and have been forced to content ourselves with results obtained upon a little more than a fourth of the area, the greater part of the irrigators having not known how to render account of what they had done, or having refused to furnish them. The tables contain:

"1. The figures which concern the plots where were obtained the largest net increase per acre."

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"2. Those which concern the plots when this increase has been least."

"3. Some examples of results obtained at the same time by proprietors irrigating surfaces of a given extent."

"4. An example of results obtained in a community where irrigation is reputed to have resulted badly."

"5. Finally the total result and the general average of the entire collection of irrigations observed."

Explaining the tables, the author says:

"We give in such case, beside the annual net increase of revenue in money, the figures of this value diminished by 10 per cent. of the total cost of first establishment. This last figure appears to us the one which gives the best idea of the success of the operation from a financial point of view, since it supposes the restoration of the capital engaged in a little less than 15 years. with 5 per cent. interest on the capital employed."

"We have abstained from giving any figures concerning the increased value of the land. It is difficult, on the one hand, to have sincere declarations on this subject, because of the fear which the treasury inspires, and on the other hand, the crisis which underlies at this moment the salable value of the property does not permit it to rest upon certain and fixed points of comparison."

In explanation of great variations in the tables, noting that one has increased his annual net revenue by $25 per acre while another's increase is but $4 per acre, he says: "It is necessary to notice that the latter is the proprietor who made least expenditure in cost of first establishment, and one of those who expend least in cultivation; he can thus be considered as having perchance, not operated very well."

"This observation appears very nearly general. It is rare that irrigations where little expenditure in first establishment is made, and above all those where slight cost of cultivation is made, give a very good result."

Twenty companies, irrigating all together 1,583 acres, gained a net profit from irrigating of $20,877.96, averaging $13.57 per acre, and ranging between $5.12 and $17.60 per acre.

I take the greater pleasure in presenting these tabulated facts from such eminent authority, because from the nature of the paper it seems to have had a limited circulation. They will bear careful study, with a view as to inferences as to profit in our own state, however different the conditions. The chief crops, it will be noticed, are hay and forage, most profitable in an arid region supplied with stock and near market, but unprofitable for distant market.

The fact must not be overlooked that the general character of the irrigation farming described is European rather than American, implying the utmost economy of labor and capital in an intensive agriculture. The results are, however, intensely interesting as giving some definite means of judging the actual advantage and general profit of irrigation.

Hoping that this slight service, incidentally resulting from my summer's journey, may be acceptable, I remain, Very respectfully yours,

GEO. T. FAIRCHILD.

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Financial Statement.

By THE BOARD.

The management of the finances of the Board has been difficult because the commissioners were set to work upon an entirely new task. No public work of this character had been previously done in this state, and there were no precedents to guide us or by which we were enabled to measure the expense of the work to be done. We were directed by the act to perform a work, the full accomplishment of which would require an appropriation many times larger than that which the act carried, because many unlooked for, unexpected and extraordinary expenses were encountered in the construction of the pumping stations, largely due to the fact that there was very little detailed information upon the geological structure of the territory in which the stations were located.

The construction of these plants under the conditions prescribed by the law, "the contract system," was unduly expensive; for instance, a contractor for a well was confronted, first, with the uncertainty of its depth and his ignorance of the strata to be penetrated.

Second, its dimensions were usually much greater than he had any experience with. Third, the necessity of accurately furnishing samples of the various strata through which he passed, and many other conditions and stipulations necessary to preserve accurate data which would be of service to others following in his footsteps; and, lastly, finding when well advanced with his contract that his machine was totally unfit for the work he had undertaken.

It is probably true with very few exceptions that the well contractors did not make day laborer's wages in sinking these wells, while the fact remains that with a suitable machine every one of them could have been sunk for less money than it cost this Board.

Again, the state was not a housekeeper on the site of the wells, to furnish "accommodations for man and beast," and hotel bills and all sorts of expenses, including hauling of materials, in some cases long distances, added enormously to the cost. Then came the pump man, whose contract included not only the cost of the pump and pipe, but the expense of skilled men at long distance from home to put them in place; the same is true of the power contractor, whose freights, car fare, transportation across the country, and the hiring of skilled men, swelled the cost in every direction.

The contractor for the reservoir figured wages for men and teams and items for delays and inconveniences which were occasioned by the failure of pump and mill to supply him with water at the time most needed.

Very many of these expenses would not enter into the cost of a similar plant constructed at the home of the farmer.

Below we give a statement, grouped under proper heads, of the expenditures of the Board up to and including the 8th of January, 1897.

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FINANCIAL SUMMARY.

Appropriation		$30,000
D. M. Frost, personal account, including salary	$2,971 81	
M. B. Tomblin, personal account, including salary	2,585 85	
Wm. B. Sutton, personal account, including salary	2,274 72	
Geo. T. Fairchild, personal account	13 95	
E. Haworth, personal account	88 39	
Stationery and printing	245 39	
Office furniture	85 35	
Postage	355 00	
Expense	497 27	
Clerk hire	805 35	
Stream measurements	571 51	
Irrigation survey under Professor Haworth, Lawrence	1,188 47	
Pump tests under Professor Hood, Manhattan	315 41	
Artesian experiments under D. M. Frost	301 58	
Apparatus, not otherwise charged	239 19	
Construction of stations	14,568 82	
Repairs to stations	1,109 09	
Experiments at stations	450 81	
Operation of stations	159 02	
Unexpended balance	1,173 11	
Total		$30,000

PROPERTY.

The Board has on hand the following property to turn over as the legislature may direct:

Plant No. 1, Hamilton county		$869 12
Plant No. 2, Gray county		789 87
Plant No. 3, Grant county		937 91
Plant No. 4, Sherman county	$2,078 23	
40 acres of donated land	400 00	
		2,487 23
Plant No. 5, Logan county	$1,503 60	
40 acres of donated land	400 00	
		1,903 60
Plant No. 8, Lane county	$498 48	
40 acres of donated land	400 00	
		898 48
Plant No. 9, Haskell county	$1,895 80	
40 acres of donated land	400 00	
		2,295 80
Plant No. 11, Rawlins county	$914 50	
40 acres of donated land	400 00	
		1,314 50
Plant No. 12, Rooks county	$641 90	
40 acres of donated land	400 00	
		1,041 90
Plant No. 13, Ford county	$927 37	
40 acres of donated land	400 00	
		1,327 37
Plant No. 14, Seward county (estimated)	$800 00	
40 acres of donated land	400 00	
		1,200 00
Plant No. 16, Hodgeman county	$1,272 08	
40 acres of donated land	400 00	
		1,672 08

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Plant No. 19, Wallace county	$588 34	
40 acres of donated land	400 00	
		$988 34
One oak cabinet letter file		50 00
One letter press, stand, etc		11 70
One typewriter		107 50
One old typewriter (useless).		
One dynamometer		237 00
A quantity of pipe		25 00
One centrifugal pump		60 00
Two well fishing tools		37 00
One case of samples of strata, in glass		100 00
One stove		16 70
Total		$18,263 60

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General Comments.

By WM. B. SUTTON.

The preceding pages have narrated the proceedings of our Board and the results which have been attained. We believe that a substantial contribution has been made to the stock of knowledge and information pertaining to irrigation by pumping; to the better understanding of the quantity and distribution of the subterranean waters of the western portion of the state; to a knowledge of the means and appliances for lifting them to the surface and storing them for future use.

What we have done we have endeavored to do thoroughly, and our conclusions have been carefully considered and are the expressions of our best judgment.

It only remains briefly to touch upon a few points which seem appropriately gathered under this head of general comments.

LOCATIONS OF STATIONS.

The first stations located by our Board were upon the unoccupied school lands of the state, as contemplated by the law. This necessitated their construction at considerable distance from any town of size or importance; largely increased the cost, and made them very inconvenient of access, and their care and operation at reasonable expense well-nigh impossible. They were not easily and conveniently seen and inspected by the people of the surrounding country. When these facts became known and appreciated by the Board, we endeavored to locate future stations close to some town of importance, giving precedence always to the county seats when located on railroads; to illustrate:

Station No. 1, Hamilton county, on unoccupied school lands, is six miles north of Kendall.

Station No. 2, Gray county, on unoccupied school lands, is six miles southwest from Cimarron.

Station No. 3, Grant county, is six miles from Ulysses; while No. 5, Logan county, on donated land, is about one-fourth of a mile from Oakley; No. 6, Wichita county, on donated land, is about one-fourth of a mile from Leoti; No. 8, Lane county, on donated land, is about one mile from Dighton, etc.

Not only did this place the stations where they could be seen and examined conveniently by a large number of people, but acquired for the state a quantity of land of very considerable value. The total of donated lands is 400 acres, the value of which is not less than $10 per acre, or $4,000.

SINKING WELLS.

Our experience in putting down wells in this territory satisfied us that it was a great mistake to let contracts to local well-drillers. We were hampered, however, by the necessity of soliciting bids separately for each station, and in awarding the contracts giving preference to those bidders living nearest the work. The well drillers in the western counties do not have suitable tools for drilling wells of the size and depth required by the Board, and those having the proper machinery and equipments lived at a great distance and could not make reasonable bids upon the stations separately.

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The Board did not feel justified in letting contracts for a large number of them in a lump, because of the experimental nature of the work to be done and the necessity of continual alterations in specifications. The trials of the well contractors in sinking these wells, the annoyances and unlooked for expenses and delays occasioned to and by them, would fill a volume. With the exception of one or two six-inch tubular wells and two or three dug wells, the process was long and tedious, vexatious and annoying to the Board and unprofitable to the contractors. Viewed by the aid of our experience, the best investment which could have been made at the beginning of our work would have been a suitable drilling machine, and the employment by the month of a skilled man to operate it, depending for common help upon the neighborhood in which the drilling was to be done. While an outfit of this kind could not have been all over the territory at once, it still could, in the two seasons, have fairly covered the whole ground, and have bored at least 50 wells in the lifetime of the Board. Such a machine would require a traction engine to operate it, but one could have been rented in almost any locality, and each well as finished might have been tested with the same power that operated the drill. We would not hesitate to recommend, in case your honorable body should decide to continue this investigation by means of wells, that you so frame the law that some such plan as this might be fairly within the powers of the Board.

A very important question is, How should a well be made in this territory? The experience and observation of the Board lead it to some conclusions on this subject. The well may be either open or tubular.

A TUBULAR WELL

Is cheaper, and answers every purpose if any one stratum of water-bearing sand or gravel is of sufficient thickness and coarseness to furnish the required water. A tubular well is made by starting with a pipe of the required size for the pump and sinking the pipe by drilling inside of it; when the drilling is finished a sand screen is dropped to the bottom of the pipe, the pipe drawn up within a foot or two of the top of the screen, and the sand screen swedged in the pipe; a working barrel is then lowered so that it rests on the sand screen; the lower valve is then dropped in place, the plunger attached to the pump rod; the well is finished, and the pump is ready to be connected with the power.

In a very large portion of our territory a single water-bearing stratum can be found which will supply pumps up to six inches in diameter, although this is not true in every locality. The one serious objection to this form of well is the difficulty of repairing it in case of accident to the sand screen. An instance in point occurred at station No. 9, Haskell county, where it was necessary to cut off the six-inch pipe and abandon about 90 feet of pipe and rods, besides the working barrel and sand screen, because they could not be pulled out. The plunger valve and working barrel can usually be drawn out without disturbing the pipe. In some instances they cannot, as when the screen has admitted a quantity of fine sand which has filled the working barrel and impacted the plunger. In case the accident is of such a nature that the pipe must come out to repair it the trouble is very serious. The pipe may be cemented in its place by sand, gravel and rock so as to render it immovable. Even if the pipe is drawn out, the well may cave and necessitate practically reboring.

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OPEN WELLS.

We think an open well is best constructed by sinking an 11-inch artesian-well casing, inserted joints, and drilling inside the casing to the bottom of the lowest water-bearing stratum. Then drop inside this casing heavy galvanized-iron casing, 9 or 10 inches inside diameter, perforated with a cold-chisel from the inside—say 72 perforations to the lineal foot from top of water to bottom of well, then draw out the 11-inch casing and suspend the pump (6-inch pipe) inside the galvanized-iron casing, and thereby utilize all the veins of water.

In case the water from the lowest stratum rises freely, a portion of the well may be filled with coarse gravel, which permits the water to pass up freely and at the same time supports the casing.

It is very difficult to insert this galvanized-iron casing in a hole made with an ordinary drill or auger without the aid of the artesian casing, as the caving of the sand makes great trouble and annoyance and occasions frequent failures. The artesian casing also insures a straight hole, a very important item in a well which is to receive a large pipe.

Fine sand, which flows almost like water and caves incessantly, is liable to be encountered anywhere throughout the whole territory, and iron well-casing following the drill or auger is the only successful way of treating it.

Mr. B. G. Lawrence, of Tribune, Kas., a man of sound judgment and much experience, who put down two wells at station No. 6, Wichita county, using an ordinary drill machine and inserting the casing after the hole was made, after finishing the second well writes us as follows:

"Just for the benefit of the public, I will say that I am thoroughly convinced that it is not practicable to put down wells so deep (145 feet) in the sand and water and use that kind of casing (galvanized iron). This well cost me every cent it came to. I have the experience for the work."

Either the tubular well, or the open well with the heavy perforated galvanized iron casing inserted through the large artesian-well casing, is easily and surely made at the location of this station, and apparently in a large territory surrounding it.

TOWERS.

The manufacturers of windmills, in their negotiations and contracts with the Board, assert and claim that their towers are of sufficient strength and so securely erected they cannot be overturned by winds which leave standing substantial buildings in the vicinity of the towers. This assertion should be taken with many grains of allowance, as several of the towers erected for this Board were prostrated by winds which produced little or no effect upon neighboring buildings, and we suggest that every newly erected tower be guyed with a strong wire extending from the top of each tower post to a secure anchor in the ground at least 100 feet distant from the foot of the tower posts and in line with them. None of our towers thus guyed have suffered.

RESERVOIRS.

Our specifications for the construction of a reservoir, *ante*, p. 13, will be found very useful. They contain our best judgment on that subject, and where strictly followed have uniformly produced good results.

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RESERVOIR OUTLETS.

We have tried different kinds of outlets. Among others a box made of 2x12-inch planks 16 feet long, the inner end sawed at an angle of 45 degrees and provided with a door hung from the top, opened and closed by a pole fastened to the door and remaining in the box. It was not satisfactory. We also tried imbedding a piece of 6-inch iron pipe secured by bolts, in the inner end of the box, screwing to this a 6-inch elbow and into the elbow a piece of 6-inch pipe which, by means of a chain, was raised and lowered. When upright the water is shut off; to let water out the pipe is lowered by turning the upright pipe and elbow to one side or other, thus immersing it in the water. This is better than the wood door, but open to the objection that in time the threads of the pipe will wear out.

The best outlet we have tried is one manufactured by the Frizell Hardware Company, of Larned, Kas., and consists of a 16-foot length of galvanized-iron pipe, on one end of which (the inner) is fastened a valve seat, which receives a heavy iron valve elongated so that the lower end does not come out of the chamber. To the top of this valve is fastened a rod and a chain, which, passing over a pulley on an upright post, furnishes the gearing for raising and lowering the valve. The chamber is also provided with a cage into which the valve fits snugly and prevents fish from escaping from the reservoir while water is being drawn off.

COST OF STATIONS.

The figures of cost of some of our stations should not be assumed as a measure of the expense of constructing an irrigation plant for private use, unless it is to be let by contract under the system which governed us, in which case there is little room for saving except in striking out of our specifications those provisions relating to the preservation of data.

An intelligent farmer, with some little idea of mechanics, may construct a plant, with water lift of 100 feet or less, equipped with 6-inch pump, 16-foot wheel, 30- or 40-foot tower, and reservoir, for a money outlay of about $500, assuming that he will perform by himself and teams all the labor, aside from that of a competent man to drill the well, put in the pump and erect the mill and tower, and will provide "accommodations for man and beast." For smaller plants the cost would be materially reduced.

There are very few 6-inch pumps in our territory upon the uplands, which fact in a measure accounts for the low average cost of windmill plants in our statistics. Again, the figures are furnished, in many instances, years after the work was done (no account having been kept), and many items are forgotten and omitted.

A 6-inch pump and 16-foot wheel, with water lift under 100 feet, would furnish the water for 10 acres of ground—not the first year, but after the reservoir becomes water-tight, the sand is all out of the well, so that water comes pure and free to the pump, and after the land has been repeatedly saturated.

The great defect in pumping outfits is lack of strength and the over-loading of windmills. Avoid all kinds but tubular pumps for deep wells.

LEASES OF PLANTS.

The irrigation law provides that the Board, when the pumping stations were completed, should lease them to responsible persons. This provision was not productive of good results.

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It requires experience, skill, watchfulness and judgment to keep a windmill and pump in constant working order. It also requires some knowledge, skill and judgment to apply water to vegetation successfully.

About a new windmill plant there is apt to be more or less breakage and difficulties; sand will cut out leathers and the pump will cease to raise water; bolts will come loose and damage result to mill; pumping rods will break, and, worst of all, the screen may admit sand and impact the plunger, and new reservoirs will leak more or less.

Some of the plants were too remote from residences to be leased.

The Board leased plants No. 4, Sherman county; No. 5, Logan county; No. 6, Wichita county; No. 8, Lane county; No. 11, Rawlins county; No. 12, Rooks county; No. 13, Ford county. Nos. 16 and 19 were completed too late for the growing season of 1896.

Some small use of the plants was made by the several tenants, but the results were not flattering, and far below what could be attained with the same facilities and more experience. The Board derived no revenue from them. The lessees of the Sherman plant, No. 4, and Rooks, No. 12, realized substantial returns for their labor.

UPLAND IRRIGATION.

Irrigation of the valleys by pumping the underflow waters of the streams has passed out of its experimental stage. This the legislature recognized in confining our operations to the uplands. Our investigations lead us to the conclusion that irrigation of the uplands by pumping the underflow waters, while yet in its experimental stage, bids fair to become an important element in the full utilization of the plains.

The quantity of this water in many localities is enormous, and it is distributed over a large proportion of the territory.

It is not practicable in our present stage of knowledge to lift water from the underflow to irrigate the whole country or any great percentage of it, but an irrigation plant of greater or less dimensions, according to the tastes and circumstances of the owner, is practicable and absolutely essential to the comfortable and successful habitation of that portion of the state west of the 100th meridian.

The present chief use of the uplands of the western third of the state is for the growing of stock, and in order that they may be utilized to their fullest extent in this business it is necessary that families reside there and that water be pumped from the earth and food grown for man and beast.

There is not one domestic animal in the western third of Kansas where, under proper conditions, five might be maintained. Nor will there be until an irrigation plant is the basis of each home.

Our investigations satisfy us that there is available water to irrigate at least 10 per cent. of the upland, which, with a fair market for the product, would make a rich agricultural and stock-growing section, and this proportion of the land will come under intense cultivation as the knowledge of the conditions is brought home to the people.

To realize the change of conditions which may be brought about by the small irrigation plant in connection with stock-growing, let us suppose that 1 per cent. of the land is irrigated. This means 6.4 acres per section, and is easily within the powers of a single windmill. This amount thus cultivated is a sure support for a family of five persons. The remainder of the 640 acres is available for stock and forage crops, and will support 30 head of cattle,

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the profits of which may be laid aside, together with the proceeds of the poultry. Assuming the counties to average 30 miles square, there would be 900 sections to the county. Five inhabitants to the section means a rural population of 4,500, or a total population of not less than 6,000. This would be the effect of the irrigation of 1 per cent. of the lands.

If a considerable number of the resident families be induced to put in irrigation plants, and thus cultivate a portion of the land to such crops as will best meet the needs of family and stock, their example will be followed by others, and the country will become more densely populated by a people comfortably situated and reasonably prosperous. Immigrants coming into the territory will begin their operations on plans that will succeed, and not, as in the past, on plans that were foredoomed to failure.

The small irrigation plant assures a home with green grass and flowers, fruit, vegetables and all the soil products of this latitude in abundance; also fish, ice, alfalfa, milk and butter, where now is nothing but bare prairie.

When the time comes that a remunerative market is at hand for the products of intense cultivation, there are both the land and the water in western Kansas to respond to the demand.

Many thousand bushels of potatoes which the people of Kansas will consume this winter were grown by irrigation in Colorado on lands worth from $50 to $100 per acre, made so by the market which Kansas with other states furnishes for them. We make our western lands worth from $1 to $10 an acre by farming them with crops that are not profitable, and make lands elsewhere worth from $50 to $100 an acre by buying their products, potatoes, etc., which our lands will produce as well. The humid parts of Kansas may grow very fine potatoes, but many people will not buy them while the Colorado potatoes are in market. The soil of the western third of Kansas, water being applied, will grow as fine potatoes as Colorado.

The American people pay about 100 million dollars per annum for sugars largely produced from the sugar beet, which will grow as luxuriantly in western Kansas under irrigation as anywhere else. The time will come when western Kansas will be more evenly than now divided between the potato, the sugar beet and the steer, and wise and judicious legislation may greatly hasten its coming.

EXPERIMENTAL FARMING.

Some of the uninformed, and some of the misinformed, and some of the unfriendly, have criticized our work and have censured us because we made no effort to farm the stations.

In the last clause of section 5, chapter 162, Laws of 1895, the Board was prohibited from doing any "experimental farming"; hence we did not plant a tree, we did not plow a furrow or raise a cabbage, and the success or failure of our work is not to be judged by the garden truck we raised, or did not raise.

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Recommendations and Suggestions.

By THE BOARD.

This Board does not desire to recommend to your honorable body whether future irrigation work shall be carried on by means of a Board of Irrigation or otherwise, but we are all of the opinion that reasonable appropriations of money should be made, that the work may not stop where it now is, but be judiciously and persistently pushed forward, believing that the expenditure of the necessary money will be wise and judicious and for the best interests of the state.

The whole subject of irrigation may be subdivided as follows:

First, Geological. The scope of geological research includes the waters, whether flowing in the streams above ground or creeping through the sands and gravel beneath. The investigation, therefore, of the water supply is a geological question.

Second, Mechanical. To the domain of engineering belongs the mechanism of lifting water, of storing and distributing it upon the surface of the ground.

Third, Agricultural. To this department belongs the practical application of water to the promotion of vegetable growth.

Fourth, Statistical. Gathering and tabulating the facts relative to the growth and importance of this branch of agriculture and presenting them in form to be grasped and understood at a glance, and in order that the legislature may intelligently determine whether further expenditure of the public funds may be wisely made in any particular direction, and if so, in what one.

The State Board of Agriculture, through its secretary, annually gathers and edits, among other things, the agricultural statistics of the state, and this department should be charged with the duty of collecting and fully and intelligently editing and presenting to the legislature and the people the statistics of irrigation.

If it is the judgment of the legislature that an irrigation commission should continue the work, and there is yet much to be done, we would suggest:

That the Board have a permanent office in the capitol at Topeka, and a clerk.

That the law should be so drawn as to permit the purchase of a proper drilling outfit and employment of a skillful man to operate it; and the making of such drillings as in the judgment of the Board would contribute most to a knowledge of the underflow waters, and in such localities as the Board deem wise to bore for artesian water.

That it should not be restricted to state school lands or any other particular lands in boring these wells, and should be permitted to make any advantageous arrangements in reference to reimbursement in whole or in part of the expense of drilling by the owner of the land, for after the water is tested and samples of the strata preserved the state would have no further use for the well, and or other power over the well nor to construct a reservoir.

That the Board be empowered to make experiments to a reasonable extent in the construction of storm reservoirs, making such arrangements with landowners as they deem advantageous.—These works after they have served their

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purpose of experiment and the data has been preserved are not of any further use or money value to the state.

That the provisions of the law be extended to the whole state.

For many kinds of crops irrigation has been found profitable in humid as well as in arid countries.

If, on the other hand, it is the judgment of the legislature that it is not best to continue an irrigation commission, we suggest that the subject be subdivided and the work apportioned among the institutions of the state best equipped to perform it, and give to them respectively reasonable appropriations to carry on the work.

We would also suggest that 20 acres of each 40-acre tract donated to the state be reconveyed to the donor: 20 acres is more than any windmill plant can supply water for.

We would further recommend that at least three of these irrigation stations, for instance, the Sherman county station at Goodland, the Logan county station at Oakley, and the Wichita county station at Leoti, be turned over to the State Agricultural College for experimental farming with an appropriation of sufficient money to fully establish and carry on the same successfully.

We would further recommend that three or four of the stations be turned over to the fish commissioner for hatcheries and an appropriation be made sufficient to conduct them successfully. A moderate price may be charged for young fish, which would go some ways toward reimbursing the state.

Finally, we recommend that, in case of the sale of any of these plants located upon donated land, the land and the improvements made by the state be appraised separately, and from any bid thereon by the donor, his heirs, executors, or assigns, there should be deducted the amount at which the lands were appraised; or that the donor, his heirs, executors, or assigns, should have the option for 60 days prior to the sale to purchase the station at the appraised valuation of the improvements thereon.

STATE AND FEDERAL COOPERATION.

The action of the legislature of 1895 in providing for an irrigation commission and making an appropriation immediately brought about cooperation between the U. S. Geological Survey and the State Board of Irrigation. The first result was the measurement of the streams—a great work, costing the state but a small sum, viz., $571.51—less than it would have cost to have maintained a measuring station upon any one of the streams. This interest of the state in work of this character was also an inducement to the employment of Professor Murphy in the work of measuring the efficiency of windmills, the employment of Professor Haworth in the investigation of the water supply in the southwestern portion of the state, and Professor Johnson, in extensive experiments with the underflow in the Arkansas valley and artesian waters in Meade county.

A continued interest on the part of the state would undoubtedly lead to further cooperation on the part of the U. S. Geological Survey, which would result in continuing their work within our borders, from which our people would derive great benefit at a small cost. Prior to the existence of the Board of Irrigation there was no authority in the state with power to negotiate with representatives of the federal government; after this Board expires there will be none. This feature of the subject is worthy of attention.

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CONCLUSION.

We are conscious that, were our work to be done over in the light of our experience, some things which we have done would be left undone, and some which we have not done would be done.

The act creating our Board was the first legislative step in a systematic effort to solve the water problem of western Kansas, and if we had been able to fully understand this work from the beginning and to carry it out to the perfect satisfaction of ourselves and all the people of the state, we would indeed have been more than human.

The field opened up by the act, and the appropriation made, confronted us at the outset with the possibility of doing a little at a great many things and nothing of permanent value in any one of them.

We have, so far as in our power lay, endeavored to avoid this, and to be systematic, painstaking and thorough in what we did attempt, knowing full well that the completion of any portion of the work would confer a more lasting benefit than many things attempted and left incomplete.

A careful study, however, of the report which we submit to your honorable body will furnish more accurate knowledge of irrigation by pumping, the extent of the western underflow waters, and of the means and cost of raising them to surface and applying them to the lands, and general information in reference to the problems which will confront the settler who expects to include in his operations the irrigation of a portion of his land, than can be found in previous literature upon the subject.

The history of the stations will warn him of the difficulties in his path, help him to avoid them, will instruct him how to put down a well, how to build a reservoir, give him valuable hints as to pumps and power best suited for his purposes, how to combine them, and knowledge of the quantity of water he may reasonably expect from the plant he proposes to put in.

Our statistics give the testimony of nearly 2,000 men actually engaged in practical irrigation, as to the returns which may be expected from irrigated lands.

Our reports upon pumps, powers, and windmills contain much new information on these subjects.

The measurement of the streams flowing out of the territory presents accurately for nearly two years the quantity of water going to waste within our reach.

The report of the geological study of the underflow water conducted under the personal supervision of Professor Haworth, of Lawrence, one of the advisory members of the Board, is the most valuable and exhaustive contribution to the literature of this subject which has so far been given to the public.

NO INTENTION TO CRITICIZE.

In nothing that has preceded has it been the intention to criticize the Irrigation law, chapter 162, Laws of 1895, or to reflect in the slightest degree upon the wisdom or judgment of the framers of that act. In fact, the longer this Board has had to deal with it and to labor under it, the more it has become impressed with its breadth and comprehensiveness. If it be the intention of the legislature to continue an irrigation board, a law can be framed with this one as the foundation, altered and amended as experience has indicated, which will be as all laws ought to be, the "perfection of human wisdom."

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TRANSPORTATION.

The Board makes acknowledgment to the officers of the Santa Fe, Missouri Pacific, Union Pacific and Chicago, Rock Island & Pacific Railway Companies for free transportation furnished to them, and in many instances to their assistants and employees, during 1895 and 1896. The transportation thus furnished has been a direct contribution to the fund, as the law gives the members of the Board no mileage, but each is entitled to "actual expenses for transportation in the discharge of his duties." All of which is respectfully submitted.

GEO. T. FAIRCHILD.
ERASMUS HAWORTH.
D. M. FROST.
M. B. TOMBLIN.
WM. B. SUTTON.

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PLATES AND MAPS.

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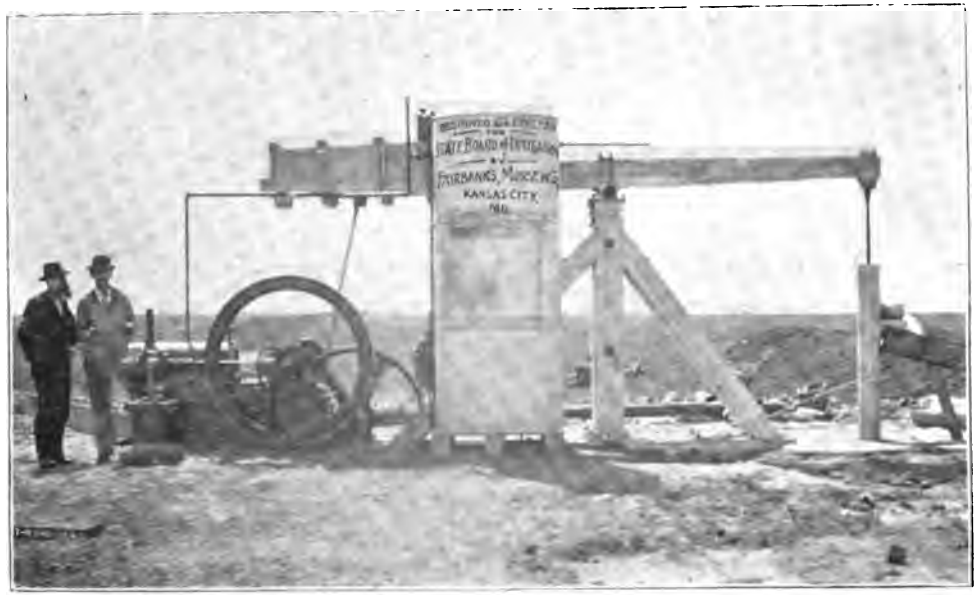

STATION NO. 4, SHERMAN COUNTY (GOODLAND.) GASOLINE ENGINE AT WORK.

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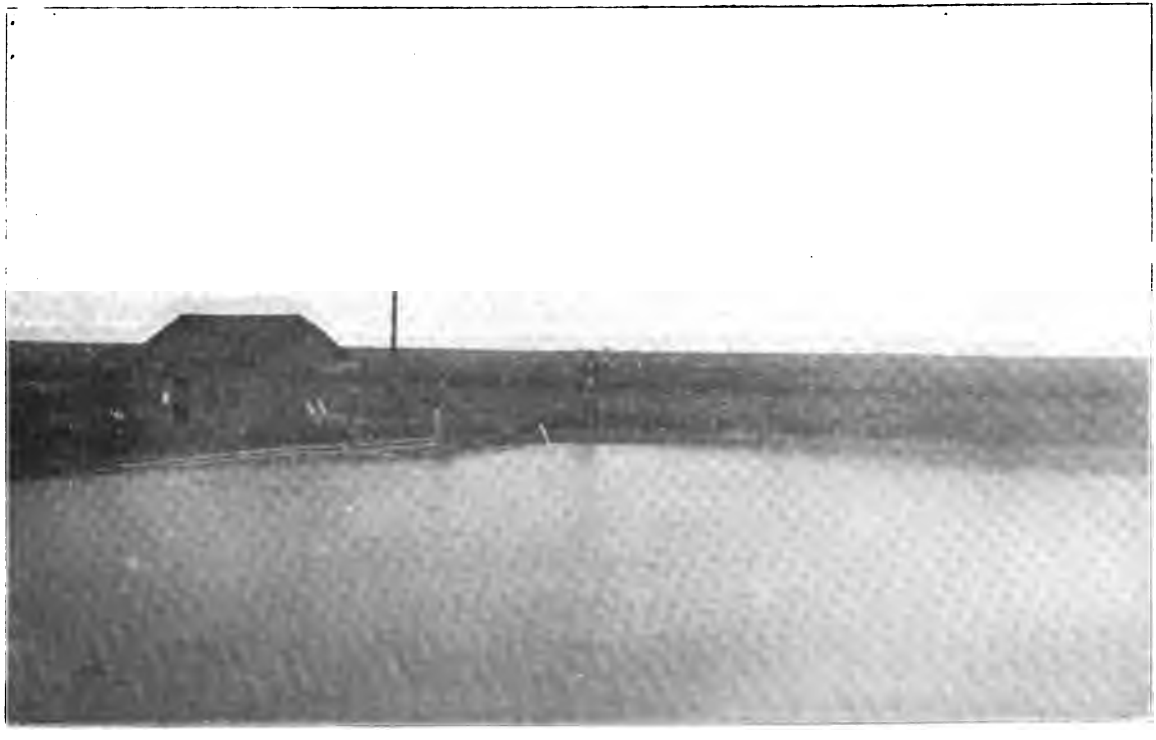

STATION NO. 5, LOGAN COUNTY (OAKLEY)
(Photographed by Haworth, 1896.)

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IRRIGATING POTATOES BY WATER BROUGHT FROM STATION NO. 5, AT OAKLEY.
(Photographed by Haworth, 1896.)

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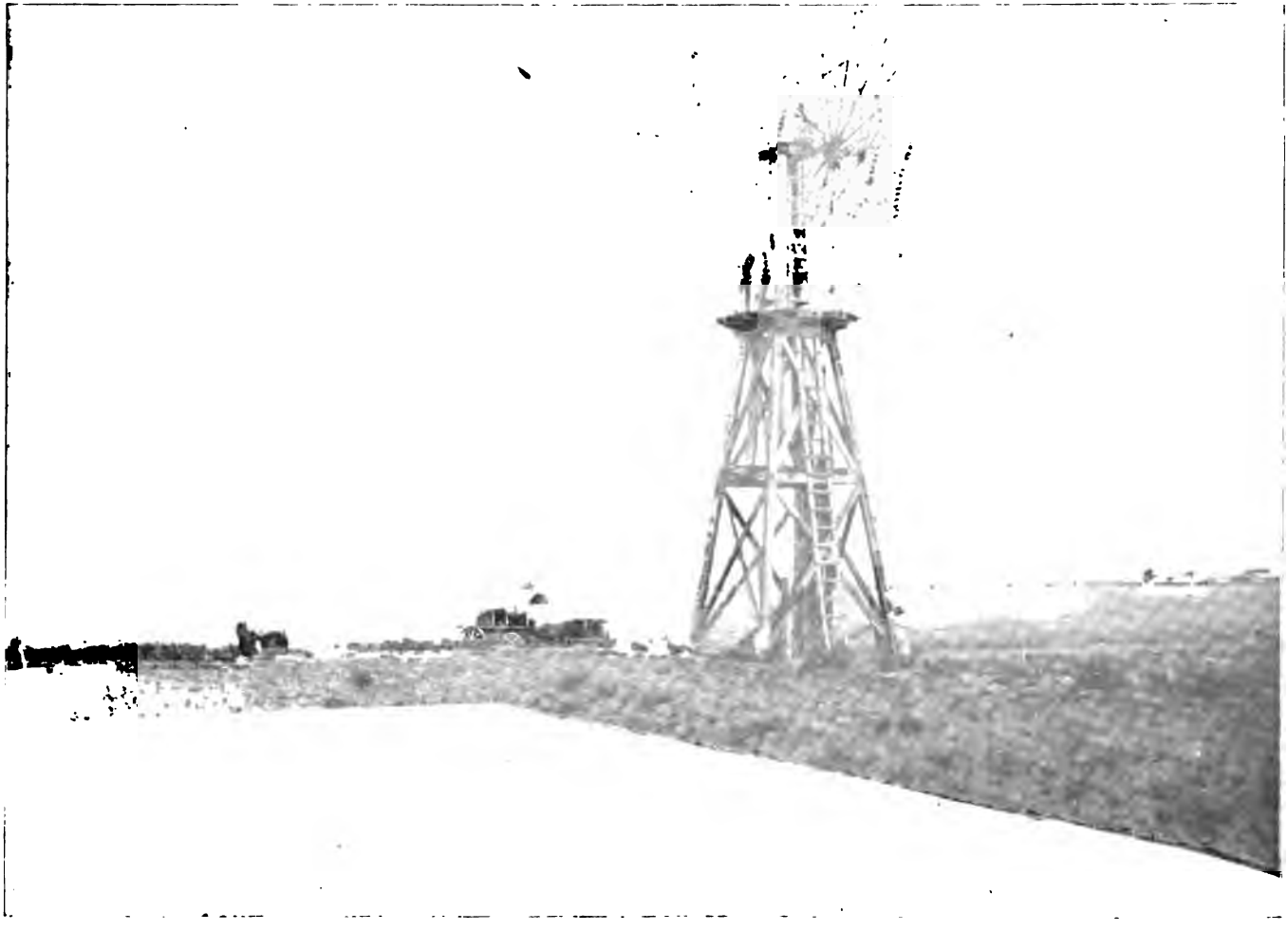

STATE STATION NO. 9, HASKELL COUNTY (SANTA FE)
(Photographed by Haworth, 1896.)

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IRRIGATION PLANT OF THEODORE STERNBERG, ELLSWORTH, KAS.

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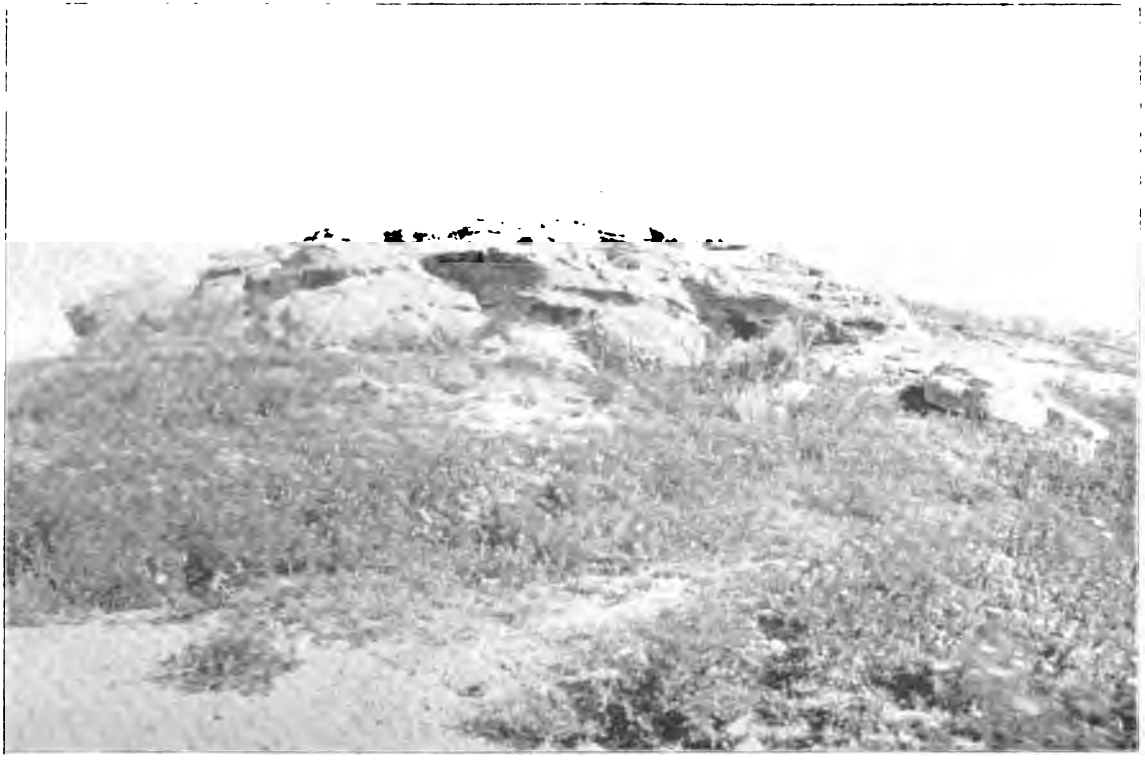

TERTIARY "MORTAR-BEDS" BLUFF NEAR DODGE CITY.
(Photographed by Haworth, 1895.)

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NEW STYLE OF "JUMBO" WINDMILL. MADE AND OWNED BY MR. W. D. SMITH, MEADE CENTRE.
(Photographed by Haworth, 1896.)

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SOD HOUSE OF THE PLAINS
(Photographed by Haworth, 1896.)

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STREET SCENE IN NORCATUR.
(Photographed by Haworth, 1896.)

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NIOBRARA CHALK, NORTON.
(Photographed by Haworth, 1896.)

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FLOWER POT MOUND, RED-BEDS OF BARBER COUNTY
(Photographed by Prosser, 1896.)

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MANSARD HILLS—RED-BEDS OF BARBER COUNTY
(Photographed by Prosser, 1896.)

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THE DAKOTA HILLS, SALINE COUNTY.
(Photographed by Haworth, 1895.)

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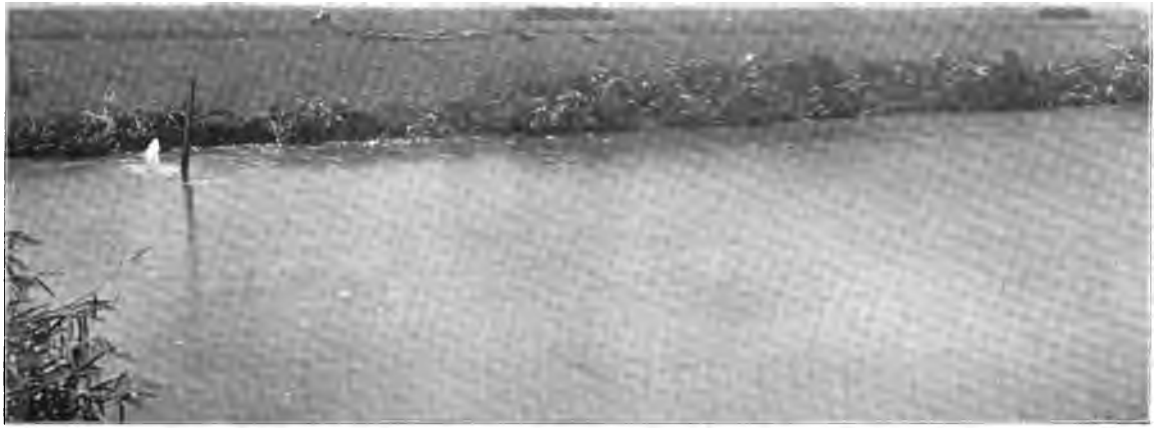

ARTESIAN WELL AND RESERVOIR OF MR. VICK, MEADE ARTESIAN VALLEY, MEADE COUNTY.
(Photographed by Haworth, 1896.)

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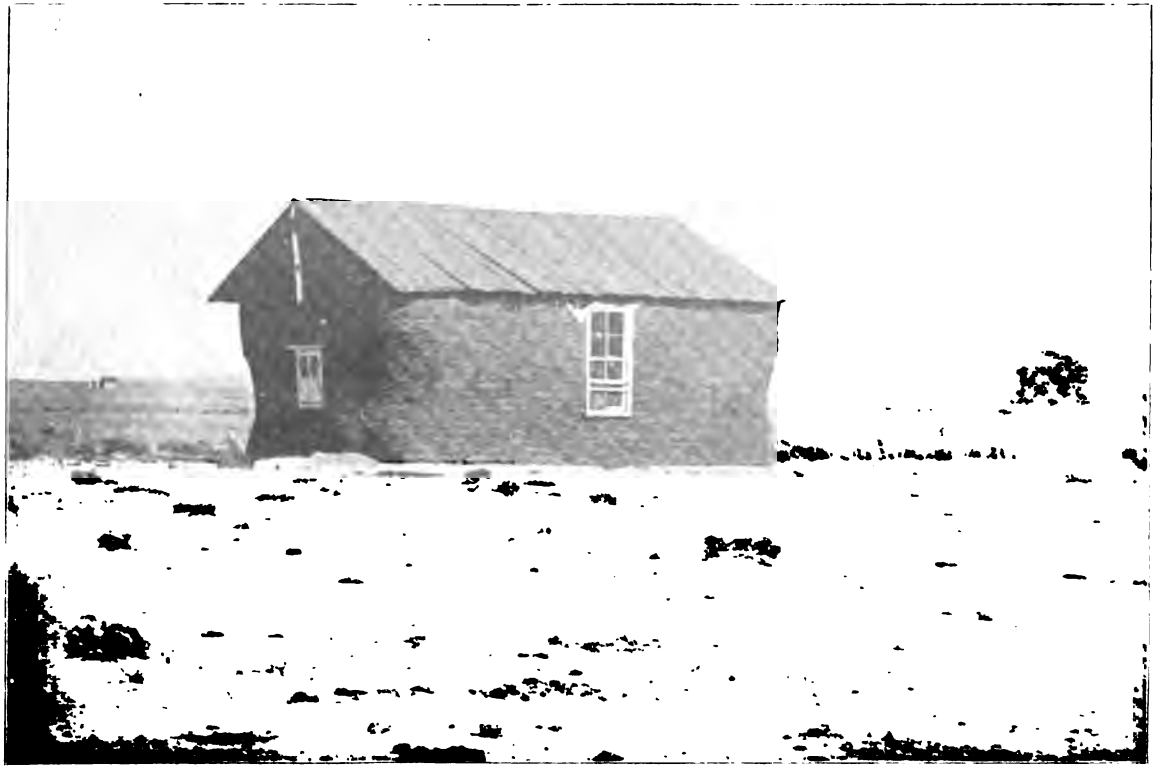

ABANDONED SOD HOUSE OF THE PLAINS.
(Photographed by Williston, 1894.)

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ABANDONED WATER PLANT OF SPRINGFIELD, SEWARD COUNTY.
(Photographed by Macomb, 1896.)

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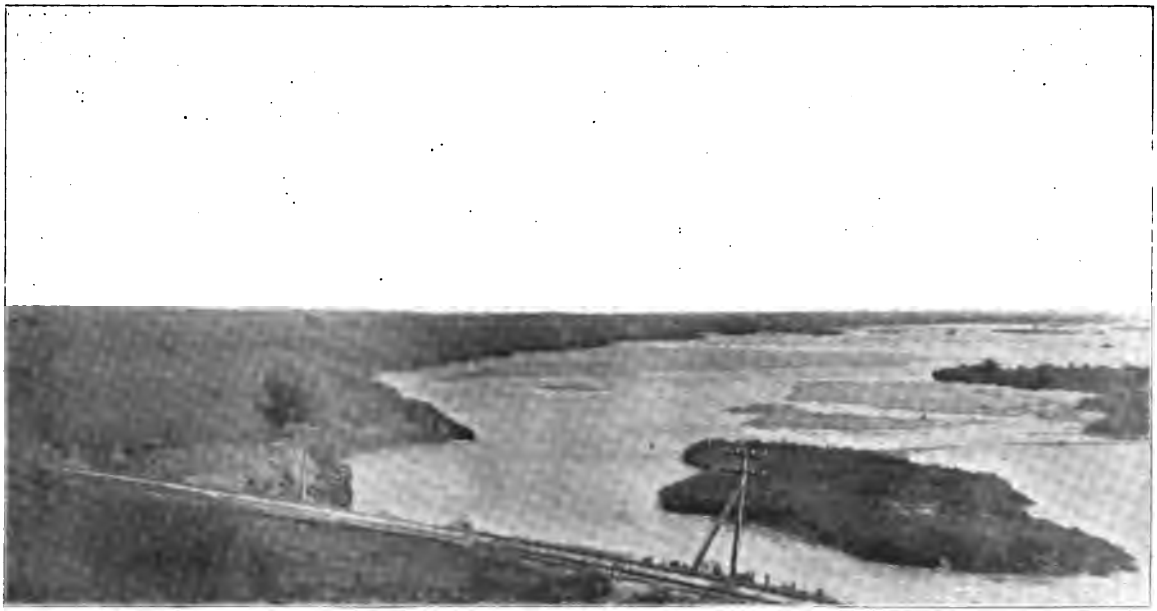

THE ARKANSAS RIVER.
(Photographed by Haworth, 1896.)

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PUMPING PLANT AND RESERVOIRS OF I. L. DIESEM, GARDEN CITY.
(Photographed by Haworth, 1896.)

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PUMPING WATER WITH TRACTION ENGINE AND CENTRIFUGAL, ON RANCH OF WM. B. SUTTON, RUSSELL, KAS.
(Photographed by Walter S. Sutton, 1895.)

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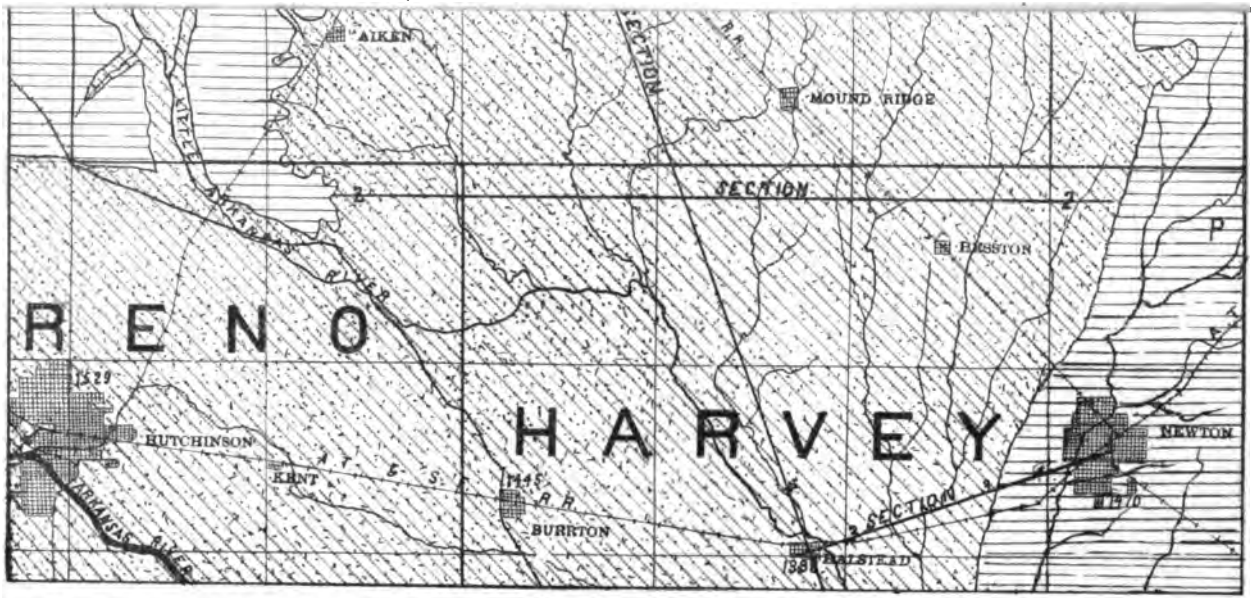

GEOLOGIC MAP OF McPHERSON AND VICINITY.

By C. S. Prosser and J. W. Beede.

Horizontally ruled .....Permian.
Solid black .....Comanche.
Heavily stippled .....Dakota.
Lightly stippled and ruled.....Equus beds—the water-bearing formation.

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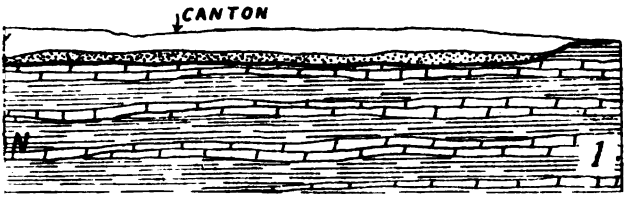

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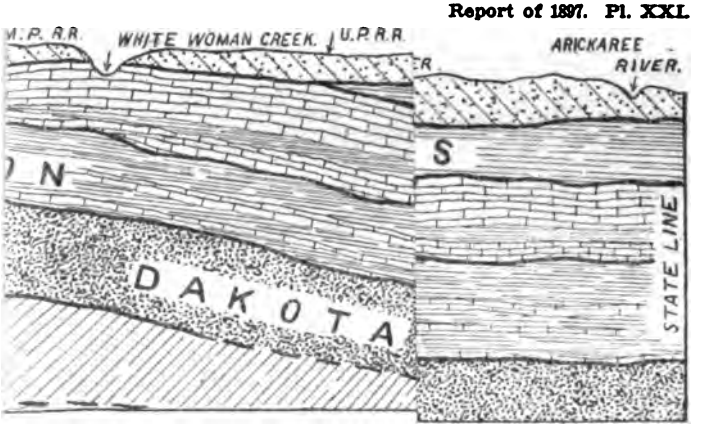

G RELATIONS OF DIFFERENT F(

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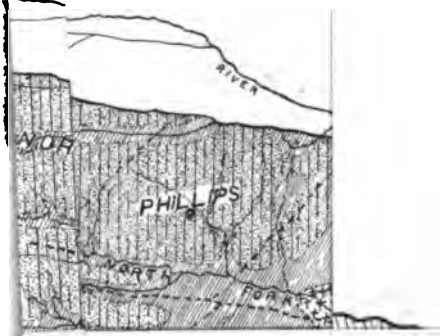

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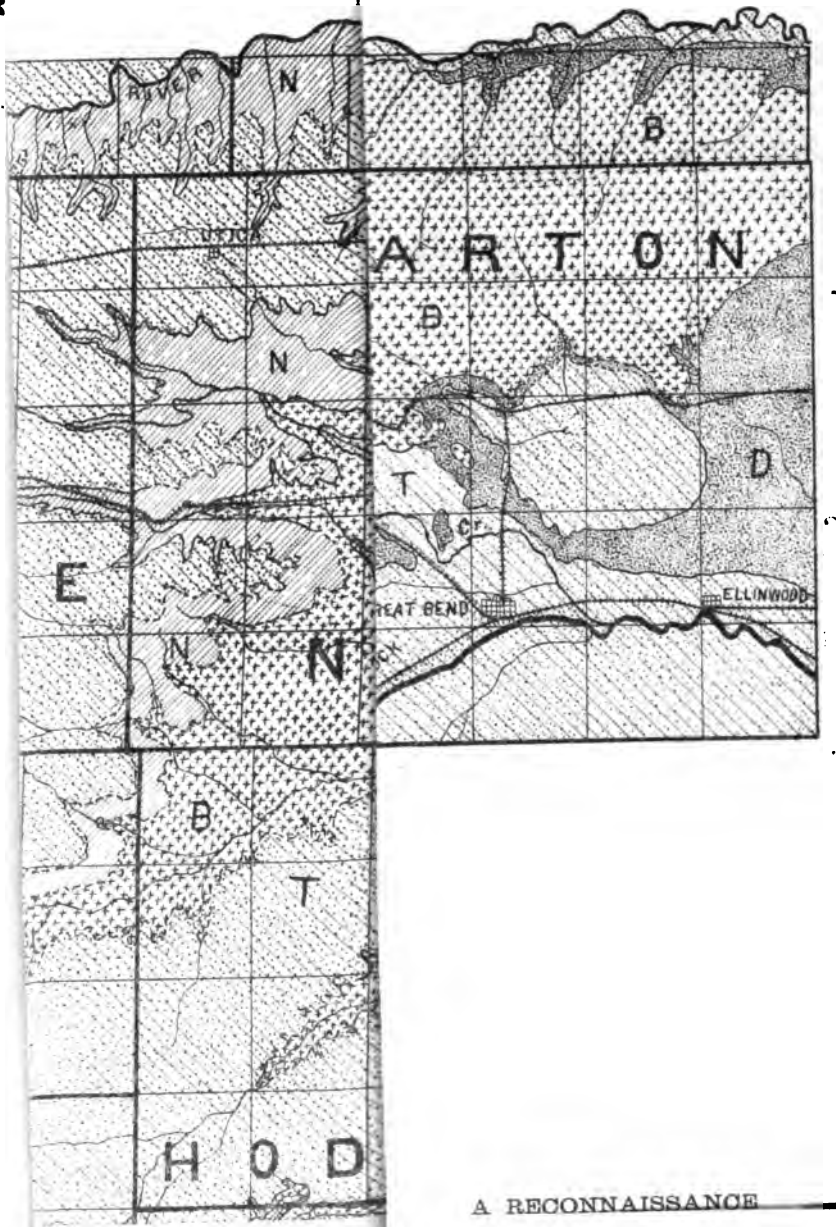

A RECONNAISSANCE

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